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AN INVESTIGATION OF LOUVERS AS A METHOD OF GUIDING JUVENILE PACIFIC SALMON

by
C. P. Ruggles* and P. Ryan

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General Introduction

Two separate problems of screening young salmon from hydro-electric power intakes in British Columbia caused the Fish Culture Development Branch of the Department of Fisheries of Canada to initiate a program of six years' experimentation with louvers.

Louvers may be generally described as a series of vertical slats placed in a diagonal line across the migratory path of downstream migrating fish. Each slat is set at right angles to the direction of flow. The migrants, upon approaching the slats, tend to avoid them while continuing downstream and thus are guided to a bypass at the downstream end of the louver line.

In 1957, 1958 and 1959 tests were conducted on an experimental louver installation on the Puntledge River in an attempt to provide a satisfactory solution to the problem of screening downstream migrating chinook salmon fry (*Oncorhynchus tshawytscha*) from the water intake canal of the Puntledge River powerhouse. Research was continued at Robertson Creek in 1960, 1961 and 1962 to evaluate the louver principle for guiding sockeye salmon (*O. nerka*) and coho salmon (*O. kisutch*) smolts from the water intake canal of a proposed hydro-electric project on the Stamp River System. Both of these river systems are located on Vancouver Island, British Columbia (Figure 1).

Departmental and B. C. Power Commission technical personnel considered various methods of deflecting downstream migrant salmon juveniles out of the Puntledge power intake late in 1955. A mechanical self-cleaning screen was considered; however, this device was found to be economically impractical because the existing intake canal water velocity of four feet per second would have to be reduced to a velocity approaching the screen of 0.4 feet per second. Alternative deflection devices such as light barriers, electrical screens and moving cable deflectors were considered, but an examination of the reports on experimental testing with these devices revealed that they would not be acceptable as a method for screening juvenile salmon at the Puntledge River. Department personnel had been following the investigation of a method using louvers which was being carried out at Tracy, California by the U. S. Fish and Wildlife Service and the U. S. Bureau of Reclamation. Preliminary results of their investigation demonstrated that striped bass and chinook fry under experimental conditions could be deflected and as a result a system of screening with louvers was installed at the Delta-Mendota Canal intake at Tracy, California. It was subsequently decided to test this method as a device for screening juvenile salmon

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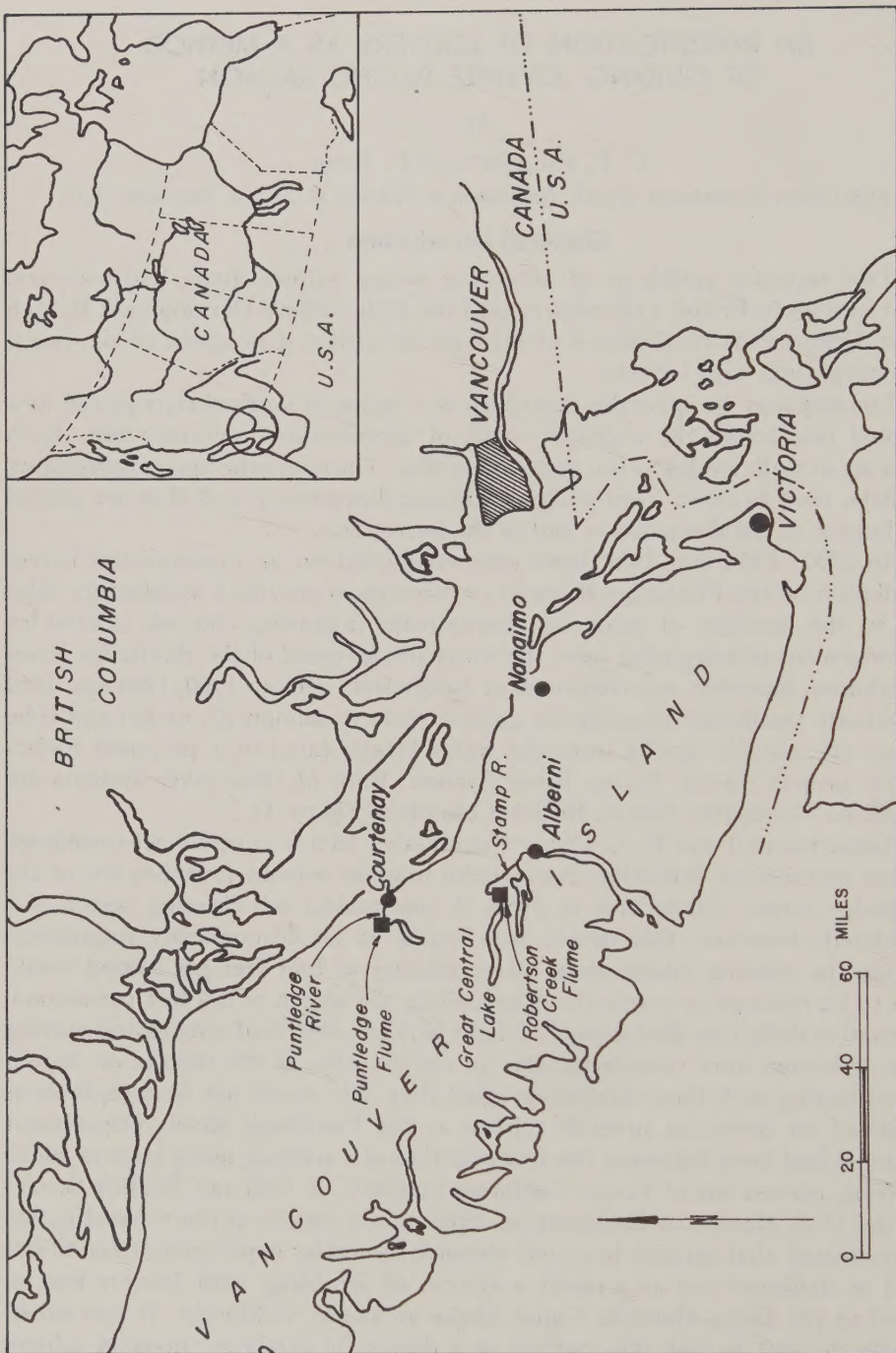


FIGURE 1. Map of southwestern British Columbia showing the general location of the test sites.

migrants first on the Puntledge River, and later on the Stamp River. A general description of louvers and a history of their development is given by Bates and Vinsonhaler (1957).

This report will summarize the results of the experiments carried out during the period of louver testing. An appraisal of louvers as a method for deflecting juvenile salmon is presented and an attempt is made to indicate areas where further research is required. The data are presented in two parts: the first, dealing with the Puntledge River tests and the second, covering tests conducted at Robertson Creek.

Puntledge River Tests

The B. C. Power Commission purchased a small hydro-electric installation on the Puntledge River in 1953 and proposed an increased development of the power potential of the Puntledge system. The new plant would utilize about 1,000 cfs compared to approximately 300 cfs used by the old plant. Investigations into the fisheries problems created by the new power development began in 1953.

The new plant was brought into operation in the spring of 1955. Concurrent with the plant opening, turbine mortality tests were carried out by technical personnel of the Department of Fisheries, Canada, and the B. C. Game Commission (now Fish and Game Branch, B. C. Department of Recreation and Conservation). Results of these tests showed that mortality to salmon and trout fry passing through the turbines was approximately 30 per cent, and to smolts approximately 40 per cent. The new power development diverted almost all the river flow into the power intake canal during the peak downstream migration period; thus making the turbine mortality a threat to the maintenance of salmon runs upstream of the diversion dam.

In March 1957 the Department began testing a panel of louvers as a possible device for guiding downstream migrants at the Puntledge power intake. These tests were carried out in a specially constructed flume on the Puntledge River during the period of downstream migration that year. Further tests were attempted in 1958, but results were not significant as the number of downstream migrants available was small, and therefore no further mention of these tests will be made in this report. In 1959 final tests were run in the Puntledge flume to verify and expand some of the results obtained in the 1957 tests.

METHODS

The test facilities were designed to intercept juvenile salmon during their seaward migration in the Puntledge River. A wooden flume was constructed in a reach of the Puntledge River between the power intake and the powerhouse (Figure 2). The flume was 10 feet wide, 6 feet deep, and 80 feet long and was designed to carry flows up to 200 cfs (Figure 3). The inside of the flume walls was lined with smooth plywood painted with a nonreflective black paint. An adjustable weir for flow regulation was provided at the downstream end of the flume, and headworks were provided for dewatering. A diversion dam 200 feet long and six feet high was constructed at the site to divert the river flow through the flume and provide the proper water depth in the flume. The general arrangement of the test flume and diversion dam is shown in Figure 4.

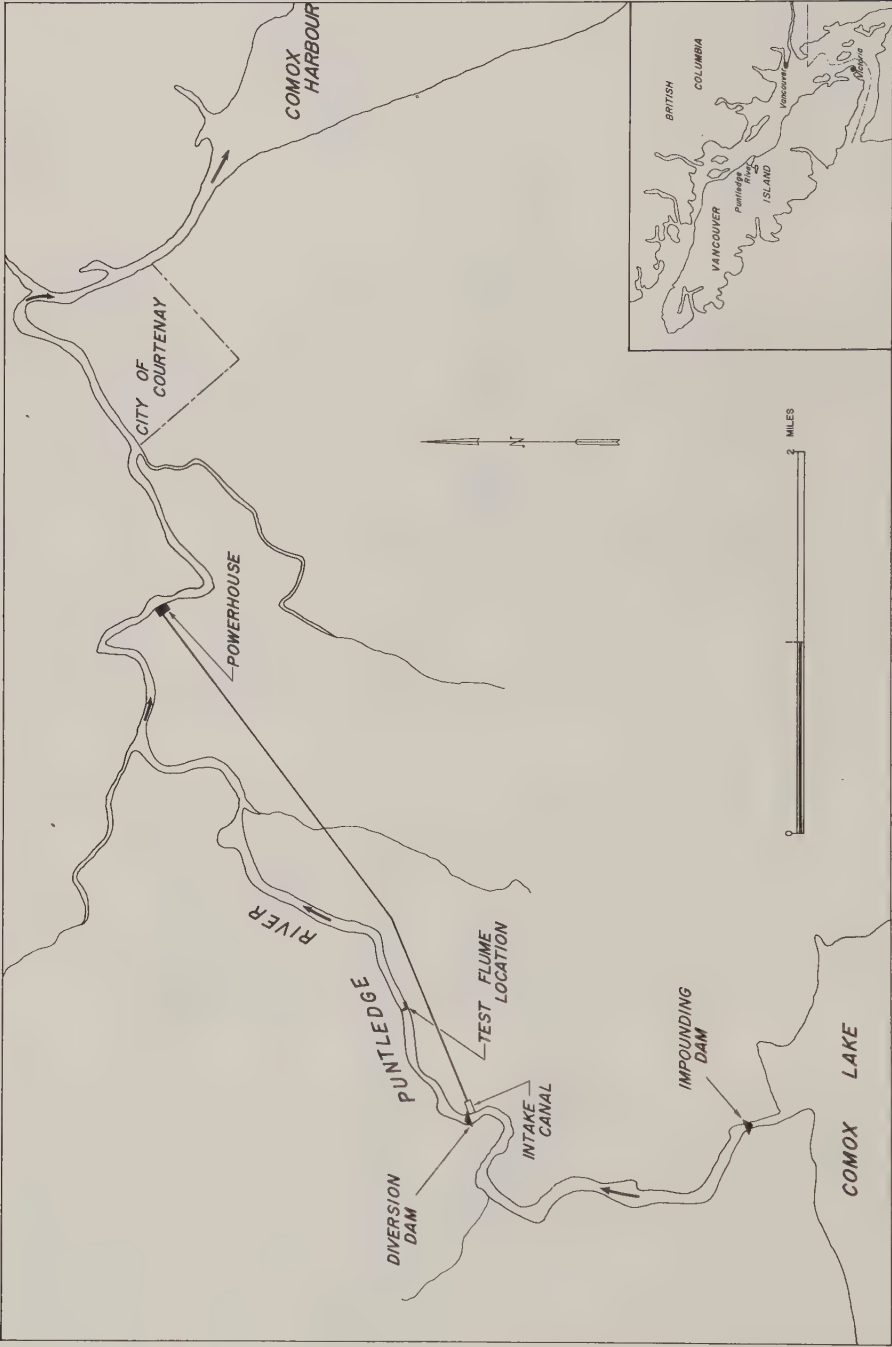


FIGURE 2. Map showing location of Puntledge Test Flume.



FIGURE 3. *The Puntledge River Test Flume with louvers installed.*

The louver line used in the 1957 tests was 50 feet long and six feet high, and made up of 22 steel panels, each a little over two feet wide. Details of these louver panels are shown in Figure 5. New louvers were installed in 1959 incorporating better designed flow straighteners (Figure 6).

The downstream end of the louver line terminated in a six-inch wide bypass which led to a holding livebox. Fish which were successfully guided entered the bypass and moved into the livebox where they were enumerated. In 1957 capture of fish which were not guided and which passed through the louvers was accomplished with three large fyke-nets, each straining the total flow passing through one-third the length of the louver line. In 1959 all the fish passing through the flume were counted by passing the entire flow over an inclined screen at the downstream end of the flume. Thus, during both years, a complete count of fish migrating down the flume and either entering the bypass or passing through the louvers was made.

Since only chinook fry migrated in sufficient numbers to give significant results, the analyses presented below pertain primarily to chinook fry migrants. These, of course, were the principal fish for which the louver device was being tested. A few steelhead trout smolts were available for testing and the guiding results on these fish will be mentioned briefly.

Chinook fry in this system and in this phase of their life cycle ranged in size from 37 to 62 mm. Steelhead smolts ranged in size from 74 to 198 mm.

Since the number of migrants and the duration of the downstream migration period seriously limited the number of variables that could be tested, a decision

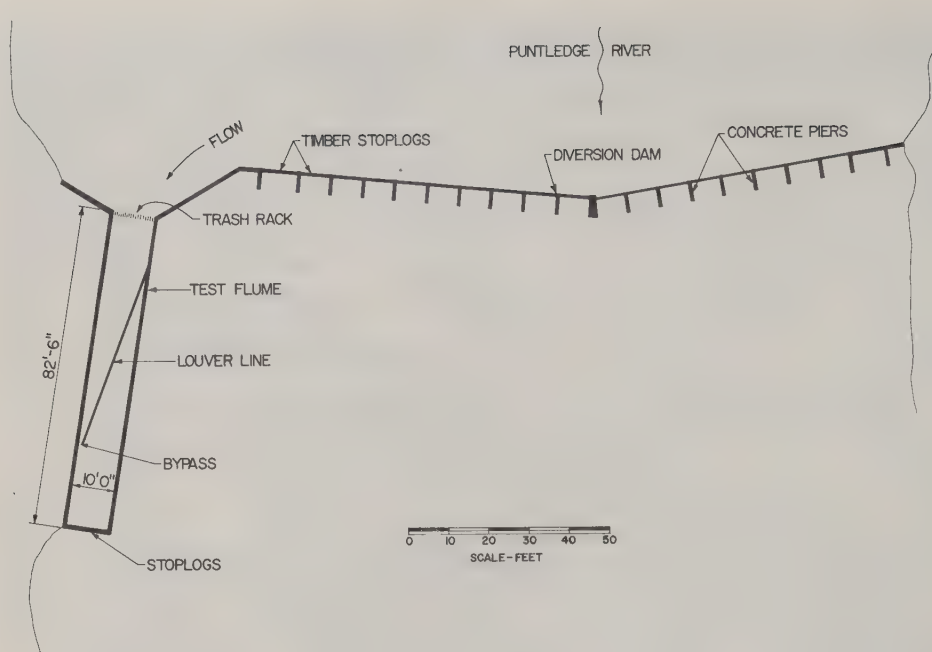


FIGURE 4. General arrangement of the Puntledge River Test Flume and diversion dam.

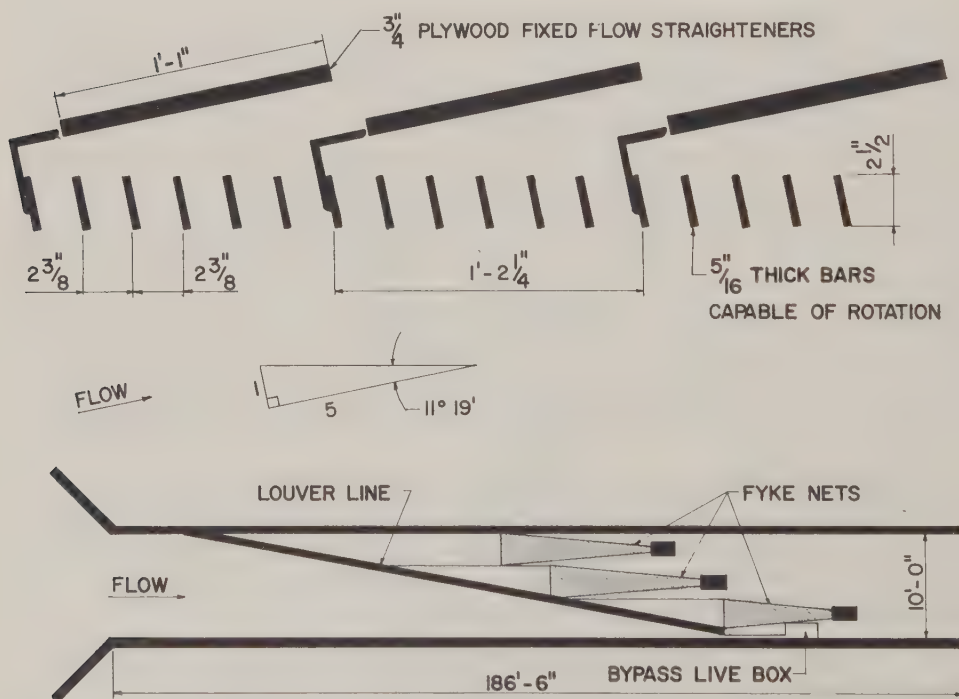


FIGURE 5. Details of the lower apparatus used during the 1957 tests.

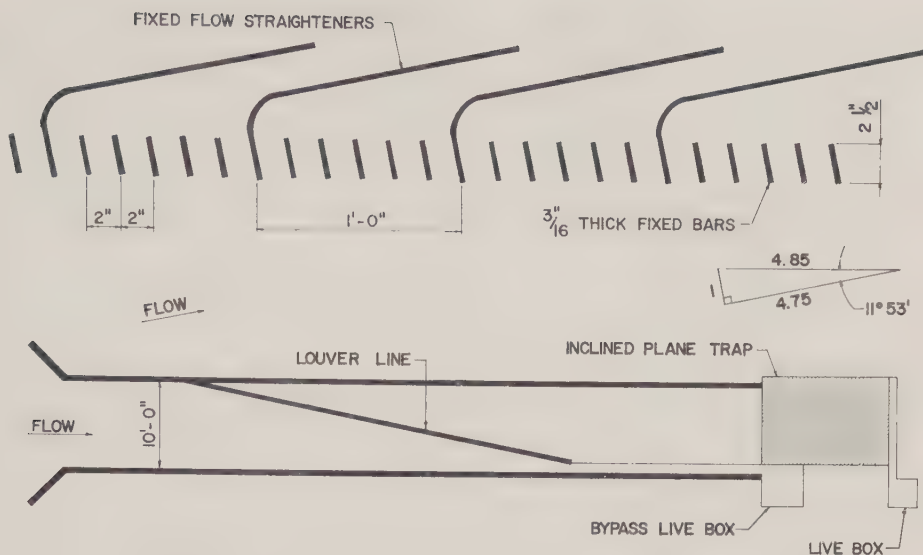


FIGURE 6. Details of the louver apparatus used in the 1959 tests.

had to be made on what variables were to be tested. The following is a list of possible variables and comments indicating the reasoning behind a decision to make them fixed or variable.

1. Shape and size of louver bars—Fixed:—Based on the California design the louver bars were rectangular in shape and were made of steel bars $2\frac{1}{2}$ inches wide by $\frac{5}{16}$ inches thick, extending the full depth of the flume.
2. Bar spacing—Variable:—Since the major problems confronting a louver installation are the accumulated trash and the loss of hydraulic head, it was decided to design the louver panels so that the louver bars could be spaced at various clear openings. In 1957, 2-inch and $4\frac{1}{2}$ -inch bar spacings were tested, while in 1959 the bar spacings tested were 2-inch and 4-inch.
3. Orientation of bars—Fixed:—Previous research in California had shown highest deflections with the face of the louver bars perpendicular to the direction of the flow. The test louver panels used in 1957 in the Puntledge flume were constructed so that the louver bars could be rotated if desired, but the guide vanes were maintained in a fixed position.
4. Angle of the line of louvers—Fixed:—The angle of the louver line to the flow in the Puntledge test flume was $11^{\circ}19'$. This was within the range of from 10° to 15° found most effective in the original research done in California.
5. Depth of flow—Fixed within limits:—It was recognized that it would be impossible to hold the depth of flow constant for all tests since only a fixed flow was available for a series of tests using a variety of approach velocities, consequently depth was maintained between four and six feet. The depth of flow in the California work was not considered to have a significant effect on the guiding efficiency of louvers.

6. Velocity of approach flow towards louvers—Variable:—This variable was considered to be the most important in the test program, since the economy of a prototype louver installation would depend almost entirely on the allowable magnitude of approach velocity. The experiments in California had resulted in the recommendation that the allowable maximum approach velocity for the Tracy louvers should be 5.3 feet per second. However, the experiments showed higher efficiencies at approach velocities less than the maximum. The maximum mean approach velocity that could be maintained for testing purposes in the Puntledge flume was 3.6 feet per second. Approach velocities from this maximum down to 1.8 feet per second were tested.
7. Width of louver bypass—Fixed:—A bypass width of six inches was chosen based on the work in California and the desire to demonstrate the economy of a prototype louver installation.
8. Bypass velocities—Fixed:—Velocities in the test flume louver bypass could not be controlled, but were a function of the approach velocity and the head loss at the louver line. The flow would always accelerate towards and into the bypass, and this situation was considered to be desirable.

After considering the above, it was apparent that only two variables were involved in the Puntledge louver tests, namely bar spacing and approach velocity. In 1957 the emphasis was placed on approach velocities, and in 1959 approach velocities were re-examined and more comprehensive tests were conducted on 2-inch and 4-inch bar spacing.

In both years the majority of the downstream migrants entered the flume during the hours of darkness. The routine procedure was to begin the tests just prior to dusk and to examine the liveboxes at midnight. If the numbers of fish warranted, the fish in the liveboxes would be counted and another test started for the remainder of the night. A total of 100 fish was chosen as the lowest number to constitute a significant test. Therefore, on nights when the natural migration exceeded 200 to 300 fish, two tests were obtained and on nights when the migration was lower, one test constituted the total night's migration. No more than two tests were carried out in any one night.

During the daylight hours, with the exception of a few days in 1957 when tests were conducted to assess the effects of louvers on daylight migrants, equipment adjustment, metering and general maintenance tasks were performed.

Control tests were run with the louver bars removed. In 1957 all the louver bars were removed, but one-third of the guide-vanes could not be removed as they were necessary for structural support. In 1959 it was possible to remove all guide-vanes as well as all the louver bars for the control tests.

The results of the various tests were expressed as percentages and showed the portion of the total number of fish migrating through the flume that were guided into the bypass.

TABLE 1—Chinook Fry Guiding Efficiency, Puntledge River, 1957 and 1959

Test No.	Date 1957	Approach Velocity	Bypass Accel.	Bar Spacing	No. of Fry	Percent Guiding Effic.	Mean Guiding Effic.
1	Apr 19	2.3	138	2	336	75	72
2		2.3	—	2	193	78	
3		2.3	138	2	151	70	
4		2.3	138	2	103	66	
5	23	1.8	138	2	138	75	66
6		24	138	2	96	62	
7		25	138	2	161	68	
8		25	138	2	147	66	
9		26	138	2	99	61	
10		27	138	2	127	65	
11	28	3.2	150	2	224	69	75
12		28	150	2	108	82	
13		29	150	2	206	77	
14		29	150	2	245	74	
15		30	150	2	246	72	
16*	May 30	2.7	141	2	112	46	59
17*		1	141	2	288	66	
18*		1	141	2	189	57	
19*		2	141	2	230	63	
20*		2	141	2	123	58	
21*		3	141	2	146	64	
22**	3	2.4	158	—	34	5.9	5.0
23**		4	158	—	90	4.4	
24**		4	158	—	28	7.1	
25**		5	158	—	112	2.7	
26	5	3.1	162	4.5	87	67	72
27		8	162	4.5	230	77	
28		9	162	4.5	147	71	
29		10	162	4.5	185	87	
30		10	162	4.5	126	70	
31		11	162	4.5	239	61	
32***	7	3.1	162	2	143	52	46
33***		9	162	2	90	41	
34***		10	162	2	109	44	
35	May 12	3.3	167	4.5	274	64	63
36		13	167	4.5	137	58	
37		14	167	4.5	234	55	
38		14	167	4.5	110	63	
39		15	167	4.5	114	68	
40		15	167	4.5	134	64	
41		16	167	4.5	100	68	
1	1959 Mar. 29	2.9	129	2	141	87	74
2		30	129	2	95	75	
3		31	129	2	157	61	

TABLE 1—Chinook Fry Guiding Efficiency, Puntledge River, 1957 and 1959—Concluded

Test No.	Date 1959	Approach Velocity	Bypass Accel.	Bar Spacing	No. of Fry	Percent Guiding Effic.	Mean Guiding Effic.
4	Apr. 1	2.5	132	2	72	56	57
5		2.5	132	2	274	60	
6		2.5	132	2	82	55	
7		2.5	132	2	150	57	
8	24	3.6	134	2	105	75	67
9	25	3.6	134	2	202	70	
10	26	3.6	134	2	93	72	
11	26	3.6	134	2	226	51	
12	27	3.4	132	4	141	54	57
13	28	3.4	132	4	124	60	
14	29	3.0	133	4	128	61	63
15	30	3.0	133	4	185	65	
16	May 3	2.5	148	4	93	76	68
17		2.5	148	4	190	59	
18	4	2.0	150	4	253	61	68
19	5	2.0	150	4	98	75	
20**	6	2.1	147	—	223	7.7	5.4
21**	7	2.1	147	—	329	5.6	
22**	8	2.6	142	—	163	1.5	
23**	9	2.6	142	—	251	11.3	
24**	10	3.0	137	—	116	3.5	
25**	11	3.5	134	—	101	2.8	

*Louver bars turned 10 degrees towards the bypass.

**Control tests with louver bars removed.

***Daylight tests on daytime migrants.

In order to assess the significance of any change in the guiding efficiency obtained under different test conditions, a common or within sample standard deviation was calculated for all valid tests conducted in 1957 and 1959. The results of the tests were subjected to an analysis of variance treatment and the within sample standard deviation obtained in this manner was then used for each test condition. The common standard deviation was used because the number of duplications of any one set of conditions was often quite low. The common standard deviation was therefore the best estimate of the average standard deviation one could expect to encounter in the guiding efficiencies if any set of conditions was repeated several nights in a row.

RESULTS

A summary of all valid tests obtained during 1957 and 1959 is presented in Table 1. A total of 66 tests was available for analysis, 41 conducted in 1957 and 25 in 1959. Replicate tests were grouped and a mean guiding efficiency for each group is presented.

1. Effects of bar spacing on guiding efficiency.

In both years, very slight increases in guiding efficiency were obtained with the narrower 2-inch spacing. In 1957 the tests run with 2-inch bar spacing averaged 71 percent guiding efficiency, while those run with 4½-inch bar spacing, averaged 68 percent. The approach velocity was not the same during these tests. However, the 1959 tests showed similar results, i.e. 66 percent guiding efficiency with 2-inch bar spacing and 64 percent with the 4-inch spacing, when approach velocities were comparable.

2. Effects of approach velocity on guiding efficiency.

In 1957 approach velocities between 1.8 and 3.3 feet per second were tested and in 1959, the approach velocity ranged from 2.0 to 3.6 feet per second. These covered the maximum range obtainable when utilizing the available discharge of 200 cfs in this reach of the river while maintaining a reasonable depth in the experimental flume.

In 1957 twenty-eight tests were carried out with five different approach velocities. The mean guiding efficiency for each of the five different approach velocities tested is presented in Figure 7-A. In Figure 7-B data from nineteen tests conducted in 1959, using six different approach velocities are graphed. Figure 7-C combines the data from both years.

From the data obtained in 1957 (Figure 7-A), it appeared as though a decrease in efficiency occurred when the approach velocity exceeded 3.2 feet per second. After the 1959 tests, the variability in these data was recognized and it is difficult to attribute any significant change in guiding efficiency to changes in approach velocity over the range of velocities tested. This conclusion becomes more apparent from an examination of the combined data of both years (Figure 7-C).

3. Effects of daytime migration on guiding efficiency.

Three valid daylight tests were conducted on May 7, 9, and 10, in 1957 (See Table I, Tests 32, 33, and 34). These tests were run with an approach velocity of 3.1 feet per second and with the louver bars at 2-inch spacing. The mean guiding efficiency obtained in these three tests was 46 percent and represents a marked reduction in efficiency from the night-time efficiency of 75 percent obtained under similar hydraulic conditions in tests numbers 11 to 15 inclusive.

4. Effects of orientation of louver bars to flow on guiding efficiency.

Although the orientation of the louver bars was not planned as a variable, observations by staff members of the Fisheries Research Board during the 1957 tests suggested that gains in efficiency might be realized by turning each louver bar slightly towards the bypass. Consequently, tests numbers 16 to 21 inclusive were carried out with the louver bars at 2-inch spacing and turned 10° from the perpendicular towards the bypass. The mean approach velocity was 2.7 feet per second.

The results were the opposite to those expected. The mean guiding efficiency dropped from an average of 71 percent efficiency with the bars directly at right-angles to the current, to a mean of 59 percent when the bars were turned from this position 10° towards the bypass.

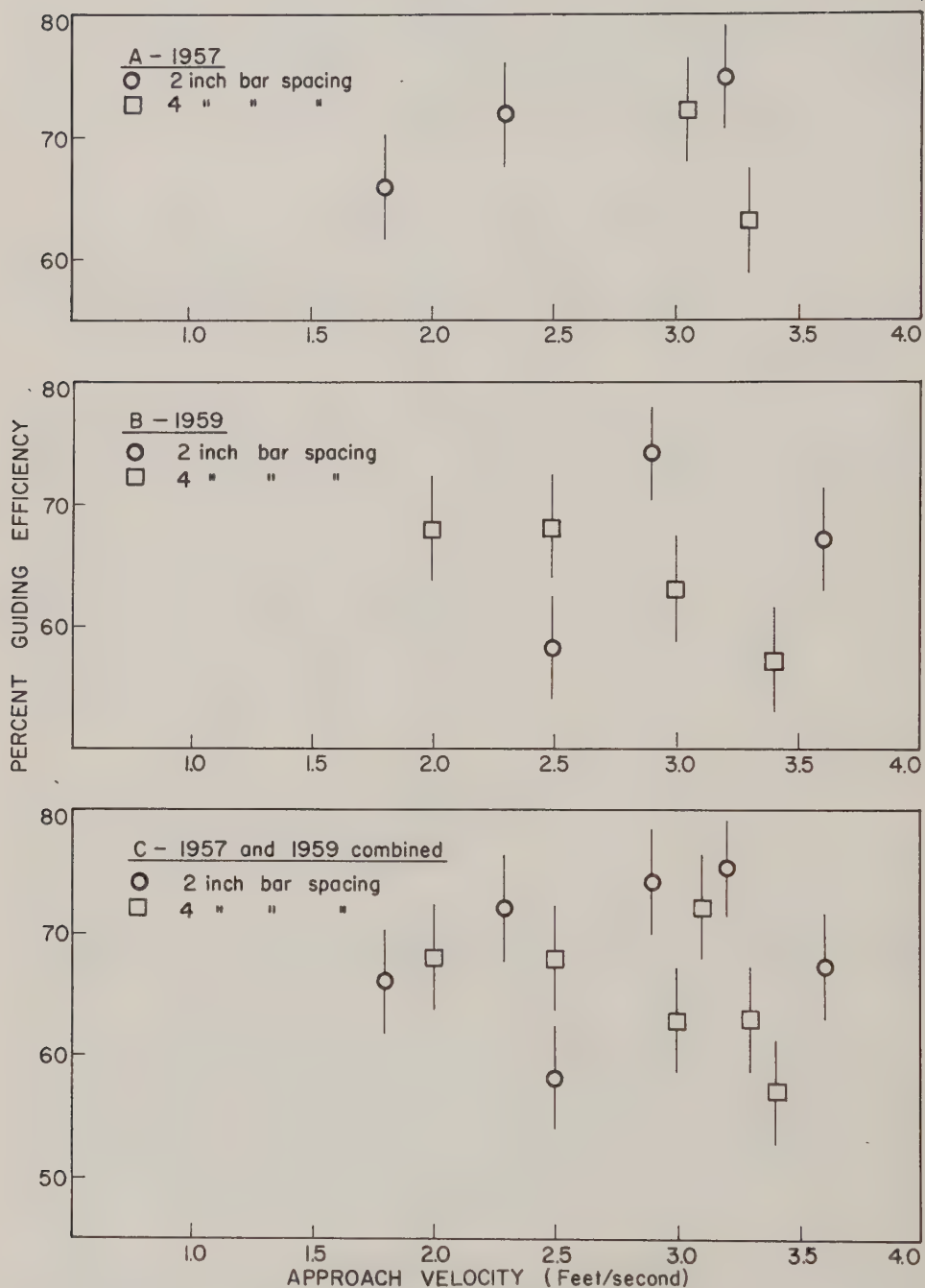


FIGURE 7. Approach velocity and mean guiding efficiency, Puntledge River, 1957 and 1959. The length of the bars represents plus and minus one standard deviation (see text).

5. Guiding efficiency of steelhead trout (*Salmo gairdneri*) smolts.

A limited amount of data is available on the guiding efficiency of louvers on both wild and hatchery raised steelhead smolts. These data indicate that the wild smolts (mean length 115 mm), were deflected by the louver array much more successfully than were spring fry, and that hatchery steelhead smolts (mean length 183 mm), were deflected, even better. The mean deflection obtained during all tests was 86 percent with wild steelhead smolts and 98 percent with hatchery smolts. A total of 766 wild steelhead smolts and 725 hatchery smolts were included in these tests.

6. Control tests.

Results of control tests for 1957 and 1959 are presented in Table 1. These data indicate a chance entry into the bypass in both years proportional to the portion of the flume width represented by the bypass, i.e. 5 percent. In 1957 the approach velocity was maintained at 2.4 feet per second. During the 1959 control tests the approach velocity varied between 2.1 and 3.5 feet per second.

DISCUSSION

The Puntledge louver tests established the range of guiding efficiencies that could be expected in the prototype installation. The results were much lower, however, than those reported for striped bass and chinook salmon fingerlings in California, and demonstrated the need for critical testing before louvers could be recommended for any specific screening problems. Although the overall guiding efficiency was relatively low for chinook fry (in the range of from 65 to 70 percent), the louvers proved extremely efficient in guiding steelhead smolts (a range of from 86 to 98 percent). This suggested that the size and species of fish involved are important factors and could influence the results obtained from any given louver installation.

In contrast to the importance of the species involved, very little significance could be attributed to changes in bar spacing and approach velocity; thus increasing the bar spacing from 2 inches to 4 or even 4½ inches had very little effect on the average guiding efficiency. Similarly, varying the approach velocity between 1.8 and 3.6 feet per second had no consistent effect on the mean guiding efficiencies.

Although the main variables tested apparently affect guiding efficiency very little over the range tested in these experiments, two other factors were revealed which did have a significant effect on the guiding efficiency.

A reduction from a mean of 75 percent efficiency for chinook fry during night-time migration to a mean of 46 percent during daytime migration occurred. This marked reduction in chinook fry guiding efficiency cannot be explained without further research. However, two possible lines of reasoning immediately come to mind. The first involves the visual response of chinook fry to louvers at various light intensities. Visual stimuli may inhibit or override the response to other stimuli that operate during darkness. The second line of reasoning would involve a basic change in behaviour of the relatively small numbers of fish that migrate during the day. Since the majority of fry migrate during darkness these atypical daylight migrants might be expected to react differently to the louvers.

The orientation of the louver bars in relation to the direction of the flow also significantly affected the guiding efficiency of the louver array on chinook fry. The guiding efficiency was reduced from a mean of 71 percent with the bars directly at right-angles to the current, to a mean of 59 percent when the bars were turned from this position 10° towards the bypass. This reduction in guiding efficiency could be explained if it were known that the fry were responding to the turbulence created by the louver bars, as the greatest turbulence occurred when the bars were set at a right-angle to the current.

From the results of tests conducted in the Puntledge flume, it was concluded that a single line of louvers leading to a 6-inch bypass would produce chinook fry guiding efficiencies between 65 to 70 percent, providing certain design criteria were followed. Furthermore, it was considered that this efficiency could be increased to a range of from 88 to 91 percent if a tandem arrangement of louvers were utilized, assuming that results obtained with the second line of louvers would be similar to those obtained with the first line. Therefore, the Department of Fisheries prepared two alternative designs for a full-scale louver system suitable for inclusion in the Puntledge intake works. Details of these designs are presented in the Department of Fisheries Puntledge River Report, October, 1958, Appendix 13 (Anonymous, 1958).

Robertson Creek Tests

During the Puntledge River tests the B.C. Power Commission announced plans for construction of a hydro-electric power development on the Stamp River System. One of the major fisheries problems associated with this development was to find a suitable method of removing downstream migrating sockeye and coho salmon from the proposed power canal intake at Great Central Lake. The intake design capacity of 2,200 cfs would take virtually the entire flow of the watershed and consequently almost all of the young salmon leaving Great Central Lake would be subjected to mortality in the turbines. It was obvious that a louver device was the only economical method which might provide a suitable solution to this problem. It was decided that a complete program of testing should be conducted to determine whether the louver method would deflect sockeye and coho salmon migrants successfully and whether increased deflection efficiency could be achieved by modification of the various physical conditions in a louver guiding apparatus. Plans were made to construct a large new test flume which would incorporate several features that were not in the Puntledge flume.

Robertson Creek, a secondary outlet of Great Central Lake, was chosen as the site for this flume (Figure 8). This location was considered ideal because test conditions would closely parallel the actual conditions that would prevail in the future power intake and the clarity of the water would make visual observations relatively easy. In addition to the value of using Great Central Lake fish and water in the experiment, the site provided economic advantages. Access was excellent and flows could be controlled by the existing dam at the Robertson Creek outlet of Great Central Lake.

As plans for a test facility progressed during the summer of 1958 two other developments affected the planning. The first was the disclosure that the Fisheries

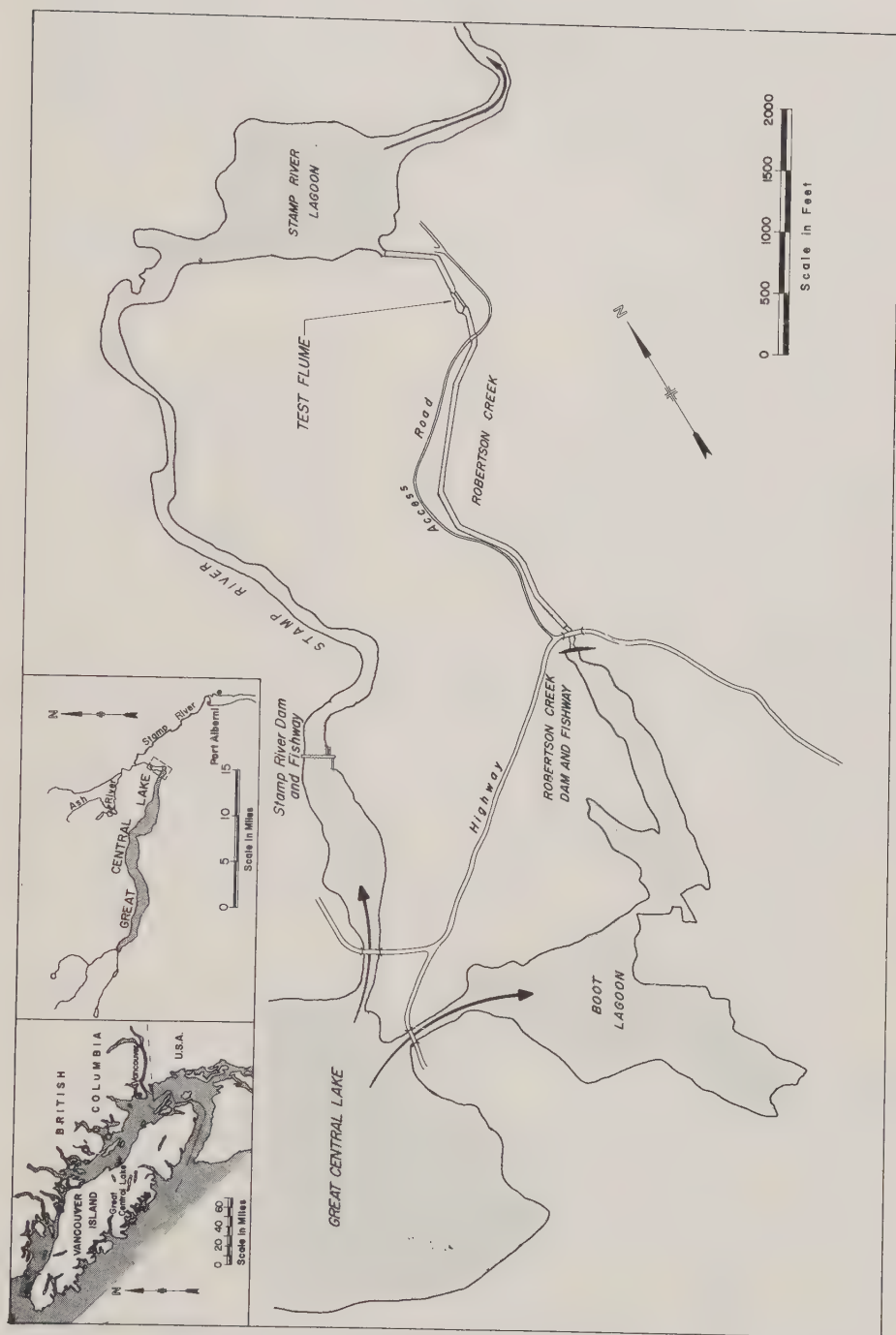


FIGURE 8. Map showing location of Robertson Creek Test Flume.

Research Board of Canada had plans to construct a test flume in this area to study the energy requirements and biochemical changes in swimming adult salmon. The second was the consideration by the Department of a plan to develop Robertson Creek as an artificial spawning channel with facilities to conduct applied research on many facets of salmon propagation. The outcome of these simultaneous developments was the combining of the Fisheries Research Board plans into the proposed Robertson Creek test flume and the integration of the flume project into the overall development of Robertson Creek.

The test flume was designed to accommodate a large variety of test installations. Considerable interest has been shown in these test facilities by individuals and agencies from several countries, and for this reason a complete description of the facilities is provided in this report.

DESCRIPTION OF TEST FLUME

The basic structure, as shown in Figure 9, consists of a reinforced concrete flume 150 feet long, 20 feet wide, and $8\frac{1}{2}$ feet deep, set against the right bank of the creek. A spillway and a 15-foot-wide bypass channel on the left side allow dewatering of the flume without interruption of the flow in Robertson Creek. As evidenced by the ancillary features described below, the test flume was designed to accommodate a variety of test installations. A general plan of the flume appurtenances is shown in Figure 10.

A removable wall 8'-6" high extending the full length of the flume was provided to fulfil the Fisheries Research Board requirements for a 10'-0"-wide structure in which to conduct its investigations. This wall was made so that it could be moved laterally to form a variable-width flume anywhere between one to ten feet wide. For flexibility and ease of handling, the wall was fabricated in panels composed of a plywood skin overlaying a structural frame of 2" x 8" timber ribs on 16" centres. Standard structural steel members were employed for the wales and bracing. Watertightness of the panel joints is achieved by means of a waterproof pressure-sensitive plastic tape which, unlike a gasket, is placed over the joints. Erection and control of the exact length of the assembled wall to fit the flume is greatly facilitated by this method of joint sealing. Figure 11 shows this wall being installed.

Two systems of lighting were installed at the flume. One provides general lighting to allow work to continue in and around the flume at night and gives a minimum intensity of two foot-candles over the interior of the flume. This overhead lighting is connected to a variable transformer to allow adjustment of general light levels over the flume for experimental purposes. The second lighting system provides low-intensity illumination on walkways and in work areas while tests are in progress. These lights, which are deep red in colour, are carefully shielded to minimize light leakage into the test area. Red lights were employed because it was believed that the colour sensitivity of the eyes of fishes shifts from red toward the green end of the spectrum as fish become adapted to the dark (Brett, 1957).

A movable gantry-like platform, mounted on rails set on top of the flume walls, spanned the full width of the structure and could be positioned, as required, throughout the flume length to facilitate visual observations, hydraulic

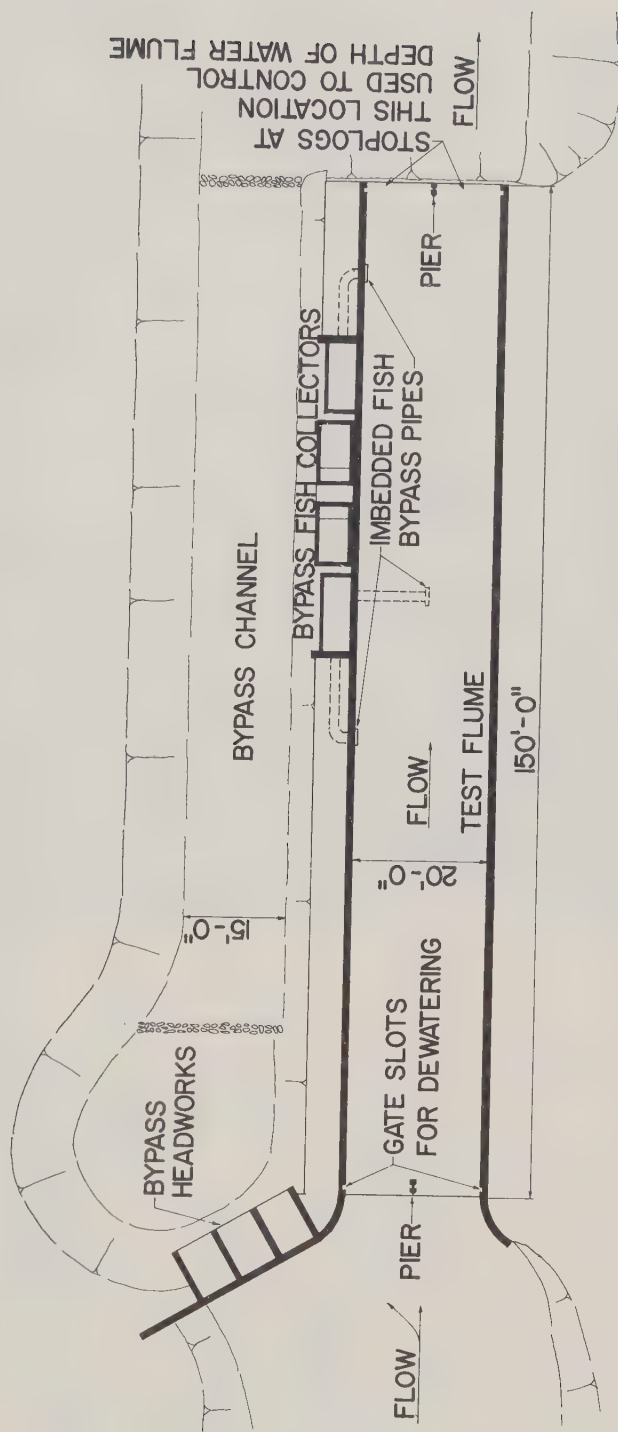


FIGURE 9. Plan of the Robertson Creek Test Flume basic structure.

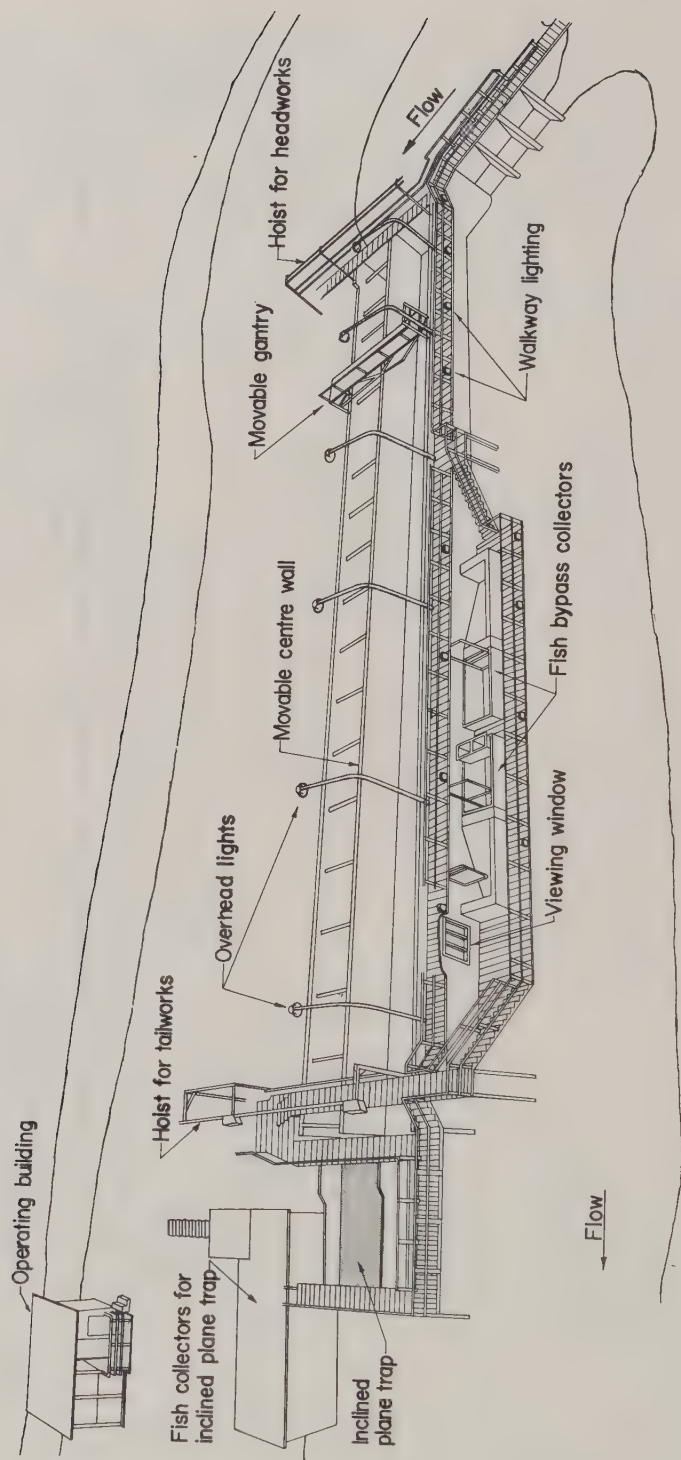


FIGURE 10. Diagram of the test flume appurtenances.

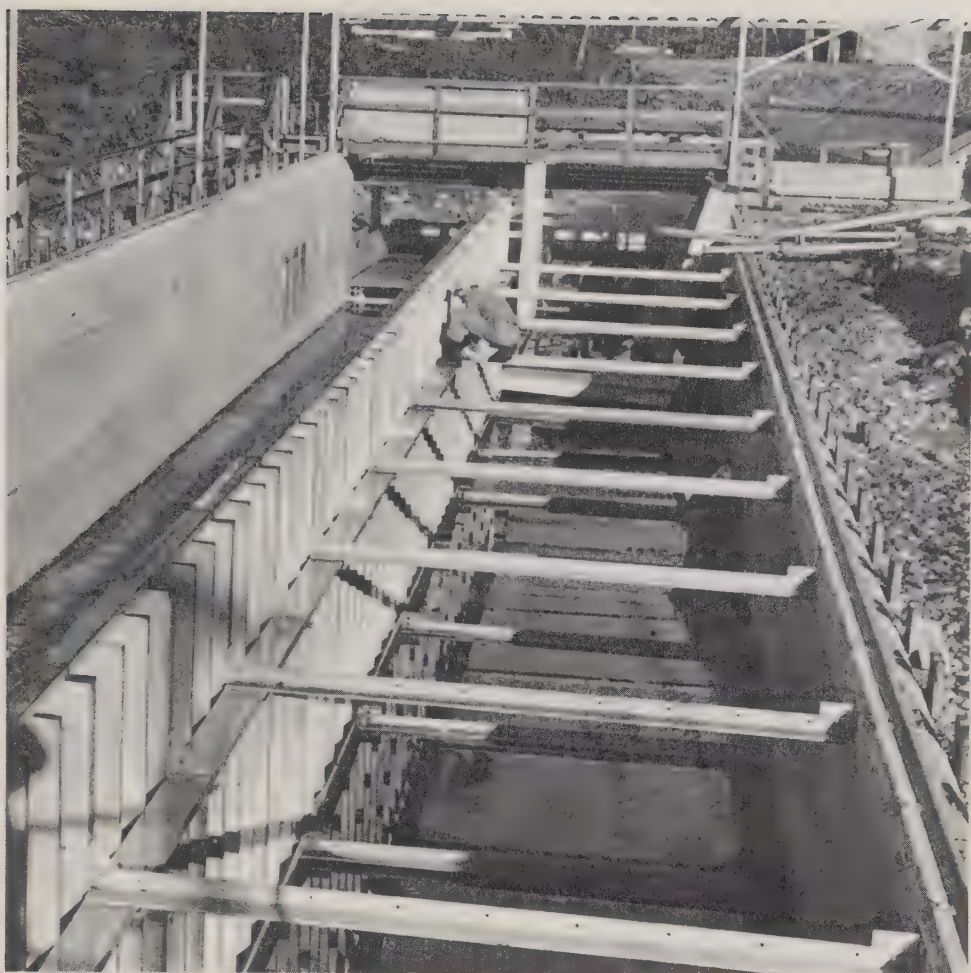


FIGURE 11. *Photograph of the center wall being erected.*

measurements and photography. Current meter measurements could be taken from a removable low-level platform fitted with a frame which securely held the current meter at any desired point (Figure 12).

Three fish bypass ducts were built into the floor of the flume to lead juvenile fish to collection facilities located beyond the flume walls. These bypass ducts were positioned in such a way that a number of louver and bypass configurations could be tested, viz. a 50' louver line in a 10' flume, leading to one bypass; a 100' louver line in a 20' flume, leading to one bypass; a 100' louver line in a 20' flume, leading to a center and a downstream bypass; two 50' louver lines in tandem, in a 10' flume, each leading to separate bypasses; and two 50' louver lines in a "V", in a 20' flume, leading to a common bypass. The bypass openings in the floor, each of which measures 6" wide by 2'-6" long, led via smooth transitions to 15-inch diameter pipes, embedded in the flume foundations, and which terminated at valves located in the collection facilities. The collection facilities, as shown in Figure 13, were designed to operate continuously with two bypasses

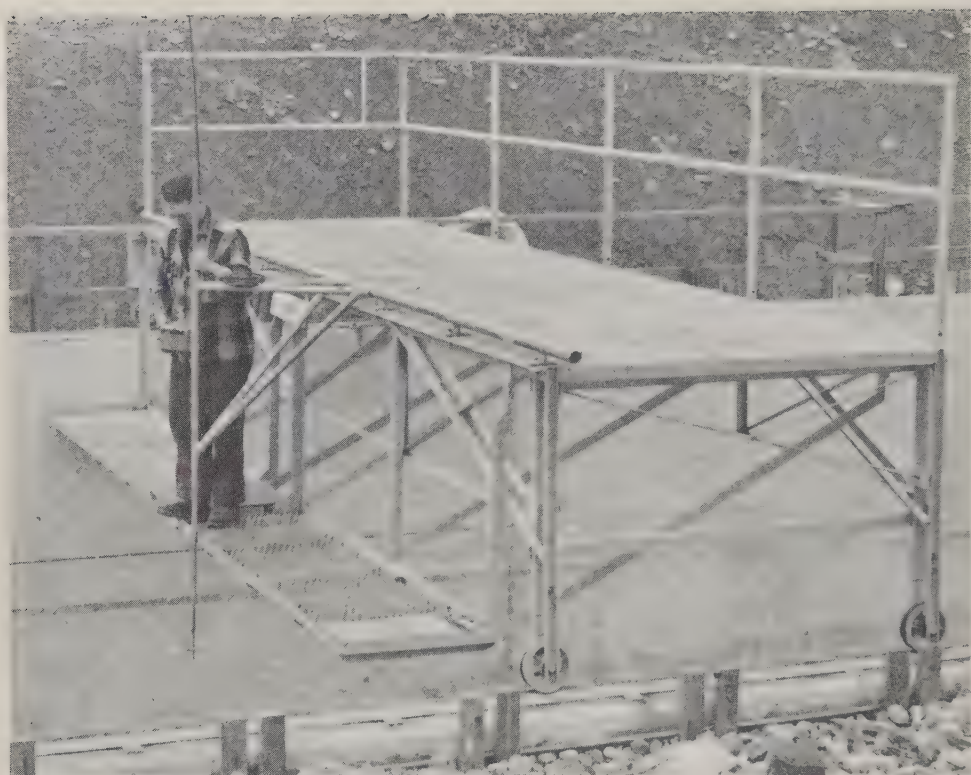


FIGURE 12. *The movable gantry-like platform used in flow metering.*

working simultaneously as would be the case when louvers are being tested in tandem. They also allowed for counting of fish to be undertaken at any desired time interval.

An inclined-plane trap (Figure 14) located at the downstream end of the flume was capable of screening out all fish of fry size and larger from the total flow in the flume with negligible mortality. This device consisted of two independent parallel sections of screening each 10' wide by 19' long, which could be raised or lowered as required by means of hydraulic jacks so that their upstream edges were flush with the crest of the stoplogs at the downstream end of the flume. These inclined-plane screens were supported at each corner by telescoping columns. Each screen could be rotated about its upstream edge so that its downward inclination in the direction of flow could be adjusted to suit the existing flow conditions. A further refinement consisted of a series of flap gates under each screen which could be manipulated to regulate the discharge through the screens. Thus, when the trap was in operation, the flap gate openings and the inclination of the screens were so adjusted to permit the bulk of the flow to pass through the screens, while the remaining water and all of the fish passed over the downstream end of the screen into a small trough. The trough was connected to the fish collection facility liveboxes by means of 4" diameter flexible metal pipes.

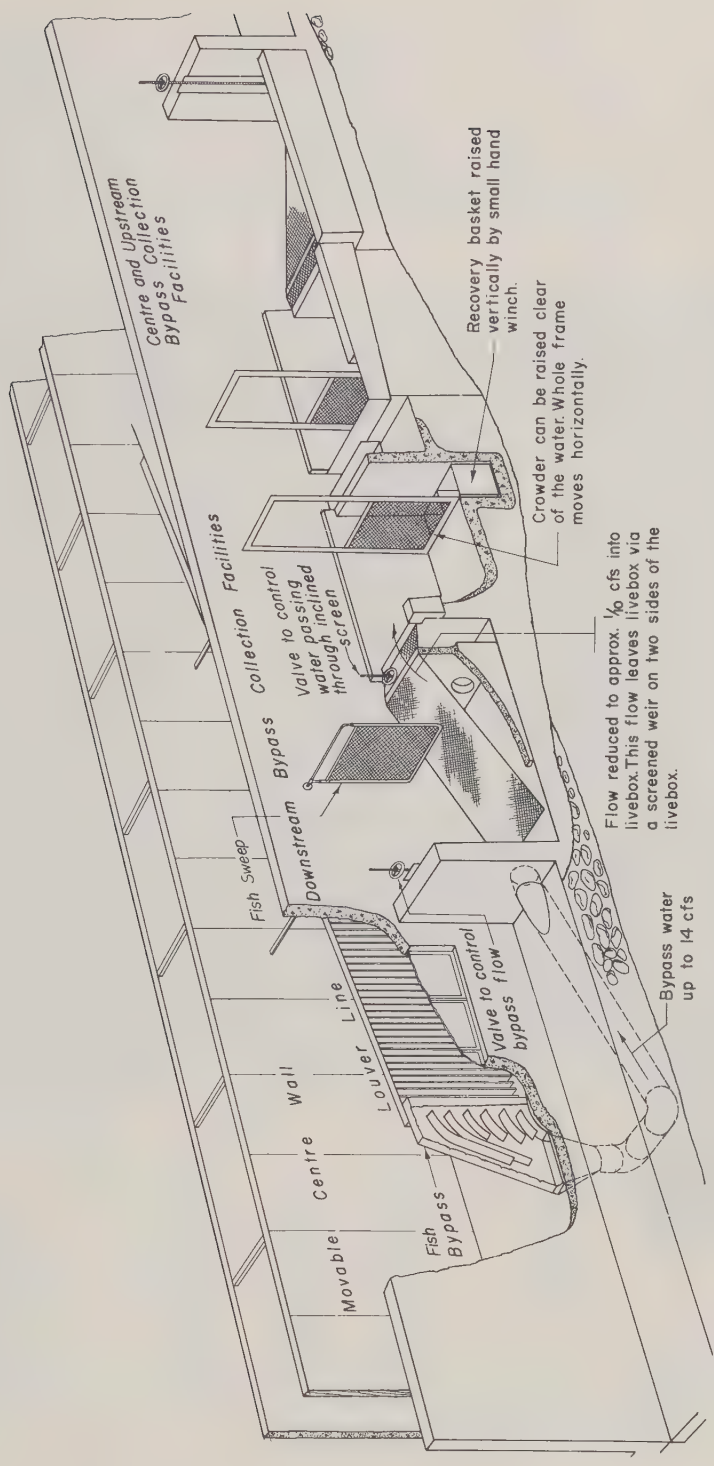


FIGURE 13. A sectional view of the fish bypass collectors.

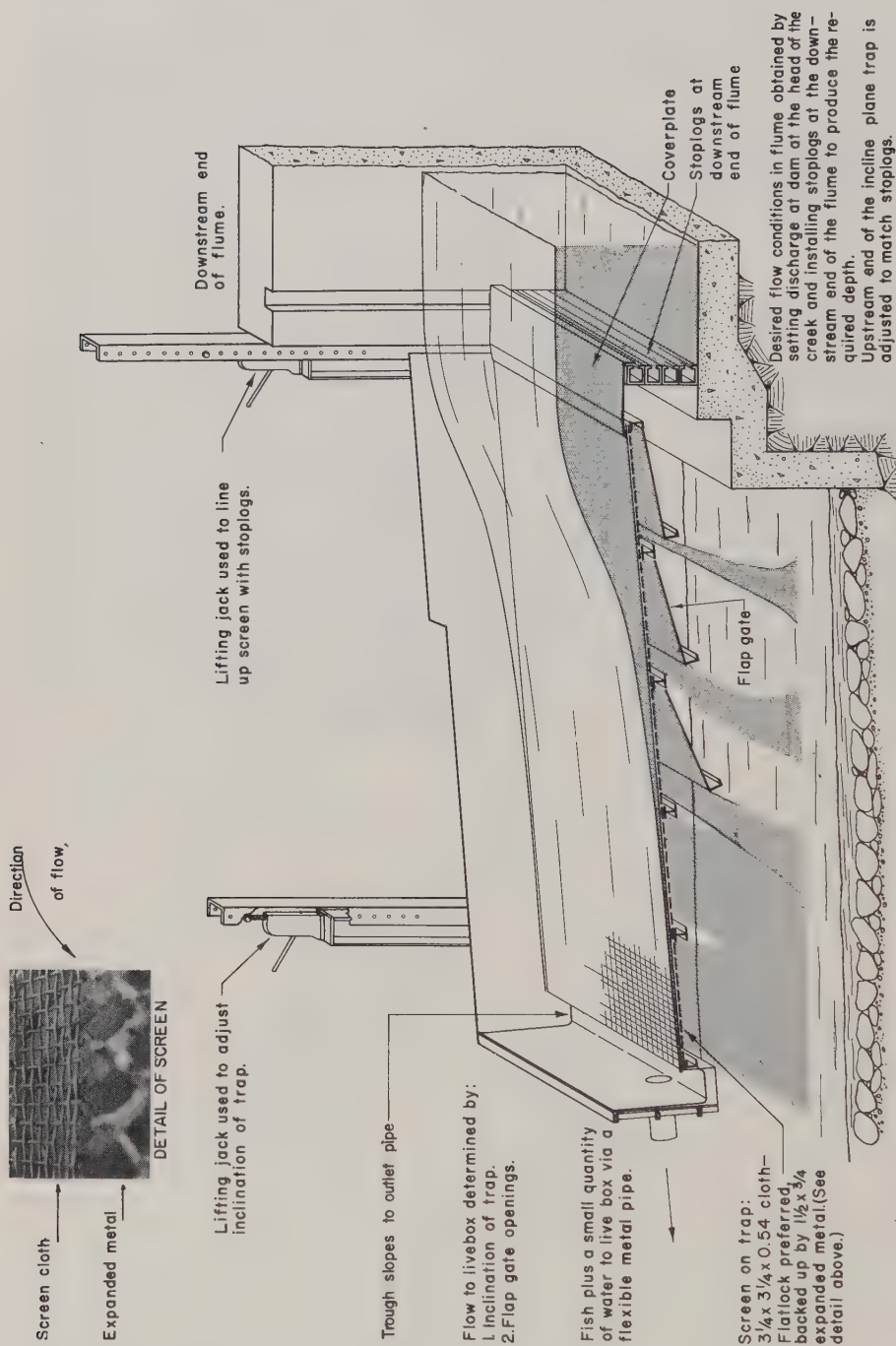


FIGURE 14. Diagram of the inclined-plane fish trap.

The fish collection facilities consisted of two concrete tanks fitted with eight screen baskets, into which the overflow from the inclined-plane traps was discharged by gravity flow through flexible pipes. As the sides of the baskets extended above the water surface, the water flow escaped through the baskets and over the sides of the tank while the fish were retained. The baskets could be raised to facilitate counting of fish. The two tanks were surrounded by walkways, and the whole area was enclosed to protect personnel from the weather and to prevent the lights required for counting and identification of fish from penetrating into the test area at night (Figure 15).



FIGURE 15. *Photograph of the fish counting shed with the light-proof wall rolled up.*

An acrylic plastic window, 7 feet wide by 4 feet high, was installed in the left wall of the flume just upstream of one fish bypass to permit observation of the vertical movement of young fish during downstream migrant guiding experiments. An observer could darken a small enclosure adjacent to the window in order to view the fish without disturbing them (Figure 16).

A small building located near the downstream end of the flume housed the electrical control panels required for the tests, provided storage for instruments, and served as an office for test personnel. The building was equipped with shutters for all windows and a light trap at the doorway to prevent light leakage into the test area at night.



FIGURE 16. *Photograph showing the viewing window in the side of the flume.*

DESCRIPTION OF LOUVER APPARATUS

The details of the louver apparatus tested during the 1959 Puntledge River program and the 1960-62 program at Robertson Creek are shown in Figure 17. Although the apparatus was designed for maximum flexibility, the following design details were fixed as a result of previous experimental work.

1. Louver line at an angle of $11^{\circ}53'$ (approx. 1:4.75) to the direction of flow.
2. Two-inch minimum center to center spacing of louver bars.
3. Louver bars placed perpendicular to the direction of flow.
4. Cross-section dimension of individual louver bars at $2\frac{1}{2}'' \times 3/16''$.

Flexibility of the louver deflector was provided by the method of assembly which was by bolting only, and in the design of the individual elements. For instance, the guide vanes double as the vertical structural members, and since the louver bars were positioned in slots spaced at two-inch intervals along the supporting steelwork, bar spacings could be made in any multiple of two inches simply by adding or removing bars. Furthermore, the plates which determine the position of the louver bars and guide vanes were reversible so that the entire unit could be assembled to deflect fish to the right or left as desired. The louver installation consisted of two 50-foot lines which could be joined to form a single 100-foot line, or a "V" as required. The louver bars could be supported at from two to five points along their length so that the effects of various degrees of flexibility could be assessed.

The floor-type bypass, which is also shown in Figure 17, was a scaled-down version of one that was developed from model studies of the proposed louver installation on the Puntledge River (Anonymous, 1958). The upstream face of the bypass had a clear opening of six inches wide by 6'-0" deep which led to the bypass pipes embedded in the flume floor.

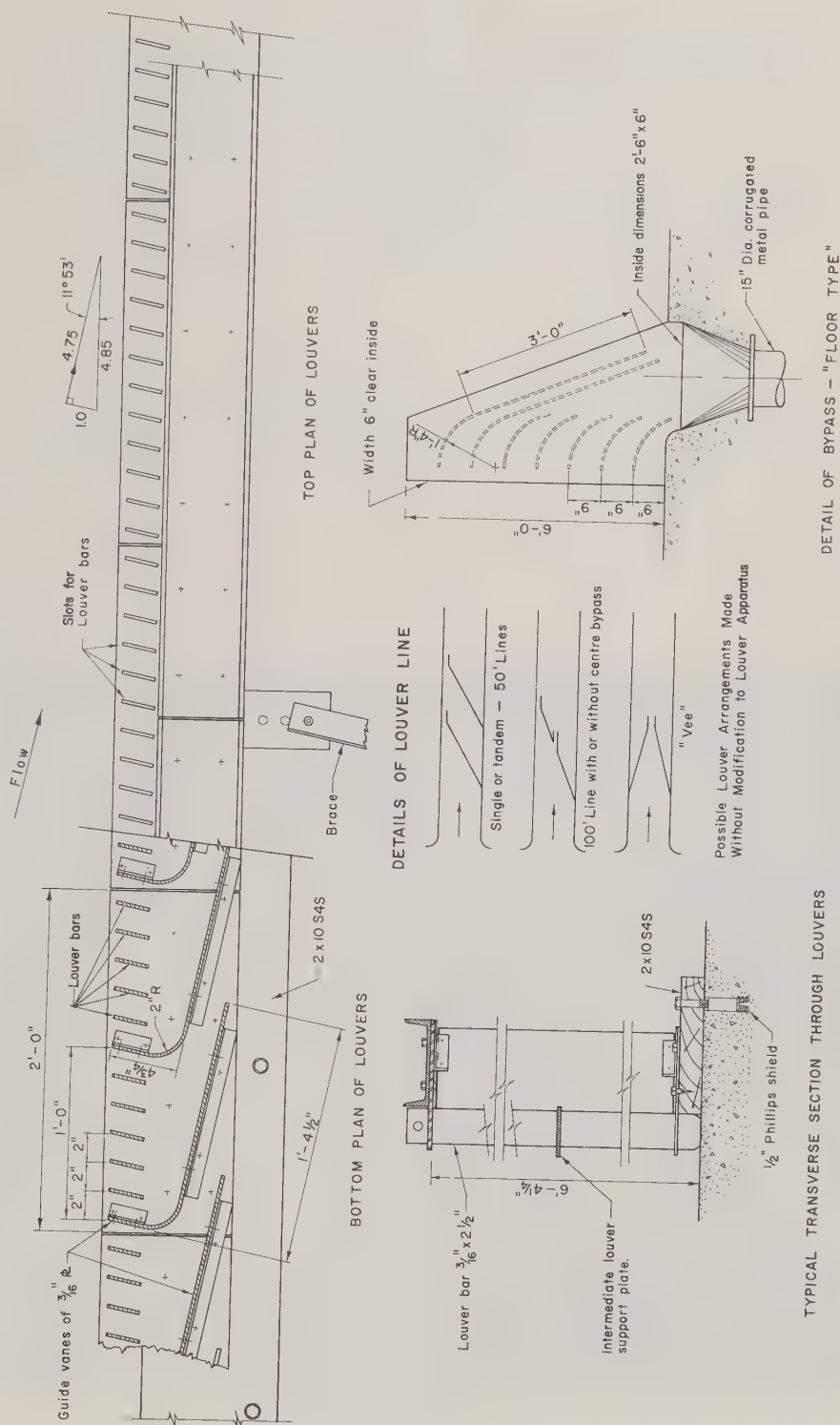


FIGURE 17. Diagram of lower deflector and bypass details.

ARRANGEMENT OF APPARATUS FOR 1960 TESTS.

A 10-foot flume width was used during 1960, in which two louver arrangements were tested. The earlier tests were conducted with a single 50-foot louver line and later tests utilized two 50-foot lines in tandem. Figure 18 shows the general flume arrangement with the tandem louver lines in position. The 6-inch-wide floor-type fish bypass was used in conjunction with the fish collection facilities described earlier and depicted in Figure 13.

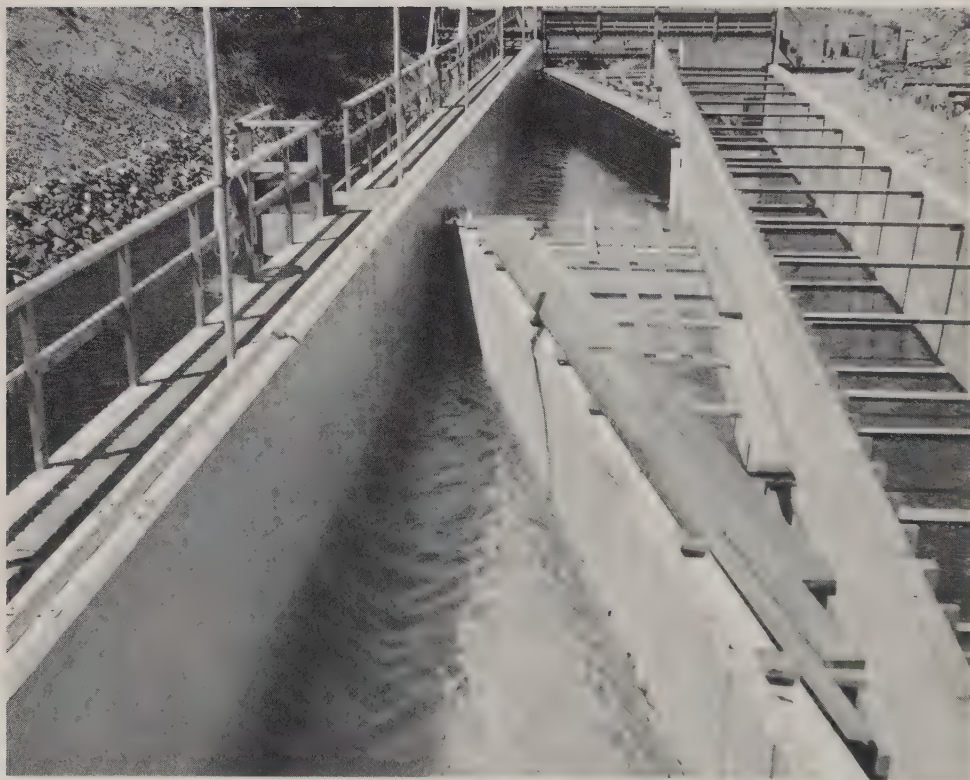
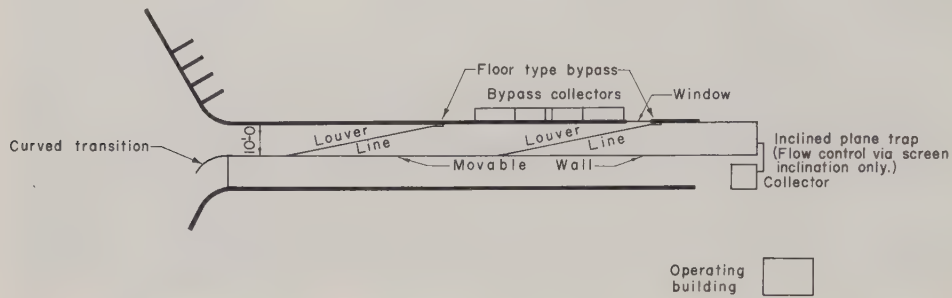


FIGURE 18. The 1960 louver test arrangement showing both louver lines installed in tandem.

Provision was made to evaluate the possible effect of louver bar colour on guiding efficiency by having one louver line painted light green, matching the flume colour, and another line painted dark red. Approach velocities in the flume could be varied between 0.5 and 5.0 feet per second.

ARRANGEMENT OF APPARATUS FOR 1961 TESTS

A number of changes were made to the 1960 test setup before the 1961 tests were initiated. As well, improvements were made to several of the appurtenant facilities as a result of some deficiencies experienced in 1960. The greatest change was the use of a 20-foot flume width in place of the 10-foot width employed in the previous year. Furthermore, the counting facilities used in 1960 to handle fish coming from the inclined-plane trap were expanded and vastly improved.

The 1960 tests showed that a variable-width bypass was required, and as the capabilities of the existing floor bypass were already limited by the head loss occurring in the embedded pipes leading to the collectors, another method had to be developed for handling the much larger flows associated with a wide bypass. A wall-type bypass utilizing a very thin outside wall was constructed to handle flows from bypass entrance widths ranging from 6" to 4'-0" and bypass accelerations of up to 200 per cent. Tests with a wall-type bypass at 6" width were expected to provide a good basis for comparison of this type with the floor-type employed in 1960.

The size of the standard Price-type current meter was such that the instrument proved to be inaccurate for the measurement of water velocities at the entrance to the 6-inch bypass, so a propeller-type meter (50 mm diameter) was purchased to eliminate this problem. This instrument also reduced the time required for velocity metering by more than half.

Observations during the 1960 tests indicated that the viewing window frames and clamping bolts caused irregularities in the wall of the flume near the bypass which resulted in impaired efficiency of the louvers, as evidenced by the fact that fish were observed to avoid these surface irregularities only to pass through the louvers. To eliminate this, a $\frac{1}{4}$ " clear acrylic plastic sheet extending upstream from the bypass for 12 feet, was attached to the wall by means of countersunk bolts. This sheet isolated the window from the flow, resulting in a smooth surface for 12 feet upstream of the bypass.

All working areas which required illumination at night during the tests were carefully shielded so that light did not leak into the test area. A sensitive light meter, calibrated in foot-candles of incident light, was employed to measure natural light in the test area. Figure 19 shows the louver arrangement employed in the 1961 tests.

ARRANGEMENT OF APPARATUS FOR 1962 TESTS

The 1962 tests employed a Vee-louver arrangement, consisting of two 50-foot-long lines leading to one bypass in the center of the flume, as shown in Figure 20. The bypass was designed to permit its width to be varied between six inches and 4'-4", and to develop high accelerations, if required.

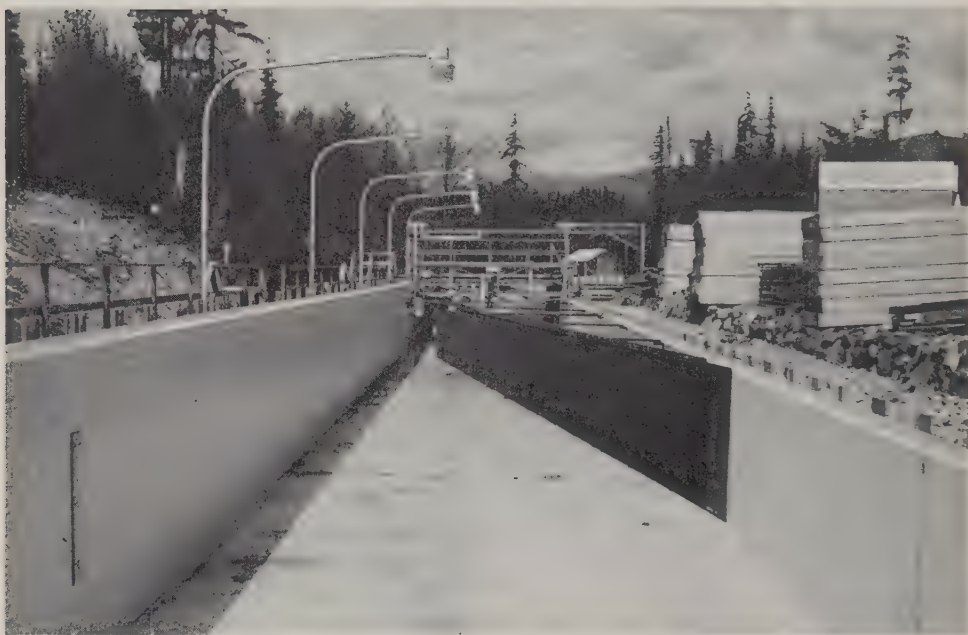
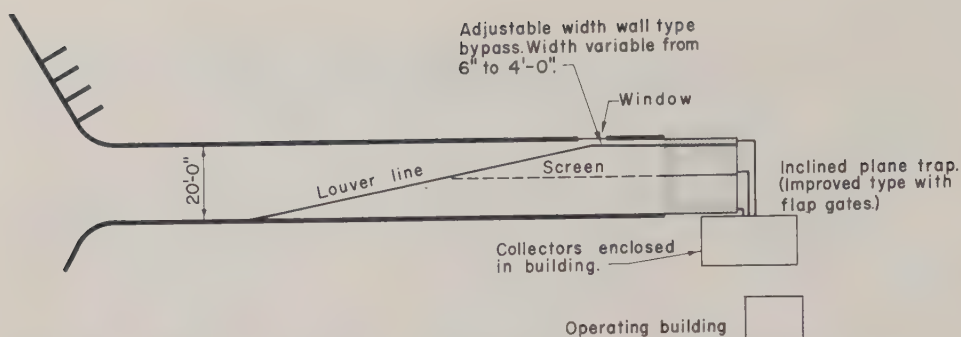


FIGURE 19. *The 1961 lower test arrangement.*

A movable wall, available for installation along the center line between the two louver lines, could be positioned so that its downstream end could be set at any position from 5'-0" inside the bypass to an unlimited distance upstream. By setting the center wall five feet into the bypass two single 50-foot-long lines, each leading to its own bypass, were created. The center wall which was 25 feet long, by four inches thick, was as high as the louvers, and to minimize turbulence, the upstream edge was rounded, while the downstream end tapered at 1 in 10, down to $\frac{1}{2}$ inch, which was then rounded off.

The screen on the inclined-plane trap was replaced after the 1961 tests with a finer mesh (8 x 8 x 0.017) so that fry could be accurately counted.

The final tests undertaken in 1962 were based on a single 100-foot-long-line in an arrangement which was identical to that employed in the 1961 tests.

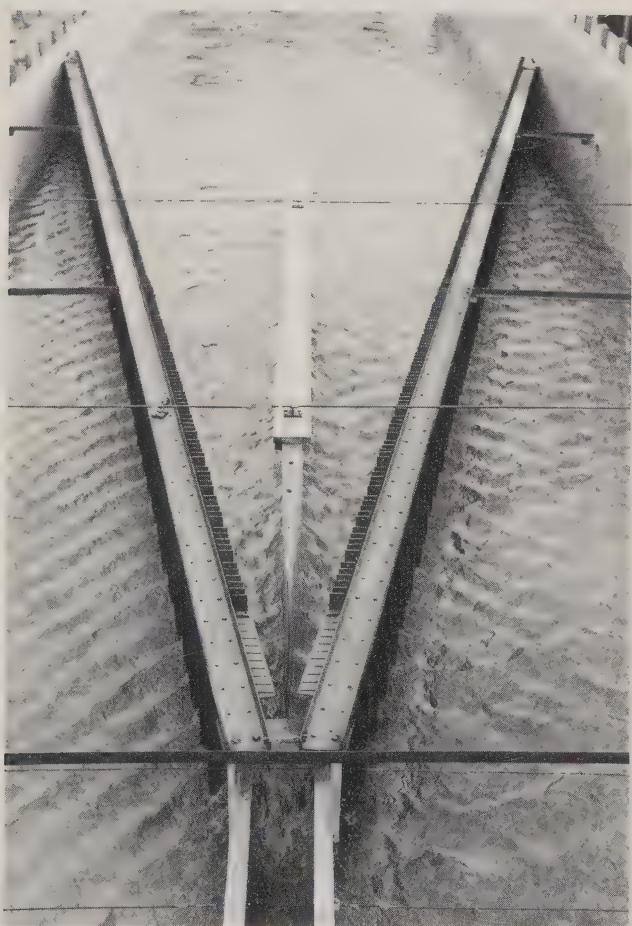
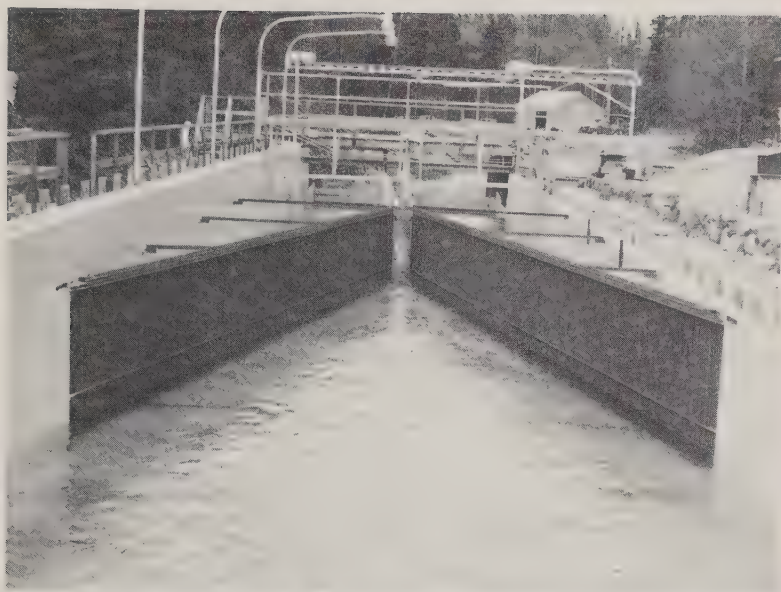


FIGURE 20. 1962 lower test arrangements with the center wall in place and removed.

The 1960 tests

It was considered, at the beginning of the 1960 tests, that a single year of testing would be sufficient to demonstrate if the louver principle could be used to provide a suitable screening arrangement for the proposed Stamp River power intake canal. The initial test results were so poor, however, that the original testing program was abandoned for the expediency of attempting to increase the guiding efficiency. Thus many changes were tried on a short-term basis and those producing desirable results were pursued, while those that appeared unsatisfactory were eliminated from further testing. The overall guiding efficiency was therefore increased, but it was difficult to accurately assess the contribution made by any one change during this period.

Certain data were obtained during the 1960 tests which formed the basis for the successful testing programs in 1961 and 1962. In addition, a double row of tandem louvers was tested for the first and only time during the complete six years of louver testing. The most important results from the tests of 1960 have been summarized and are outlined as follows:

1. Factors considered responsible for increasing guiding efficiency.

a) Dark red louvers gave higher guiding efficiencies than did light green louvers. The inside of the flume was painted light green and perhaps the contrast of the red louvers against the pale green background was the important factor in their success.

b) The removal of turbulence caused by a discontinuity in the flume wall in the vicinity of the bypass mouth increased the guiding efficiency of the louvers. The projecting edge of the viewing window frame caused turbulence in the otherwise smooth flow along the flume wall towards which the louvers converged. Visual observations showed that sockeye and coho smolts would often attempt to avoid this turbulence and in so doing, dart through the louver bars. When this projection was smoothed with a fillet of putty-like compound, the smolts would more often continue uninterrupted into the mouth of the bypass.

c) Increasing the bypass velocity so that an acceleration occurred into the bypass seemed to have a beneficial effect on guiding efficiency. When a reduction in velocity occurred at the mouth of the bypass, fish were reluctant to enter the bypass and a loss in guiding efficiency occurred. It was impossible, with the 1960 bypass facilities, to provide positive acceleration into the bypass at approach velocities greater than 3.6 feet per second. This proved to be a serious handicap in evaluating the effects of approach velocity on guiding efficiency since the bypass acceleration tended to decrease as the approach velocity increased.

2. Tandem louvers.

A tandem arrangement of louvers was tested near the end of the test period and the results serve to illustrate the guiding success obtained with sockeye smolts of both single and double lines of louvers. The approach velocity varied between 2.9 and 4.1 feet per second during the eight tests that were conducted.

Separate bypasses were provided for each louver line in order that efficiencies could be calculated for each bank of louvers as well as the total efficiency for the combined tandem array.

A total of 969 sockeye smolts passed through the flume during the eight tests. The first louver line deflected 728 of these fish, or 75 percent. The second louver line deflected an additional 141 sockeye smolts. This represents a guiding efficiency of 58 percent on fish which had been unsuccessfully deflected by the first line of louvers. The combined guiding efficiency of the tandem louver arrangement was therefore 90 per cent.

3. The bypass problem.

It was observed during the course of the 1960 tests that most of the loss of fish through the louver array occurred in the vicinity of the bypass. Schools of sockeye and coho smolts were repeatedly observed deflecting from the upstream portion of the louver line and reached the general vicinity of the bypass mouth relatively intact. The schools, at this point, sounded and many of the individual fish refused to enter the bypass, dispersing upstream. These observations demonstrated a decided reluctance of schooling sockeye migrants to enter a bypass as narrow as 6 inches.

DISCUSSION

There was no indication during the period of the Puntledge River tests that the bypass width was a critical factor in the successful deflection of chinook fry. Furthermore, reports from louver tests conducted in California suggested that even a 4-inch-wide bypass was acceptable to striped bass and chinook salmon fingerlings. The observations made during the 1960 Robertson Creek tests indicated that the bypass width could be a critical parameter when attempting to deflect schooling sockeye and coho smolts.

The 1960 tests revealed many of the practical problems associated with large-scale louver deflection tests carried out in the field with a naturally migrating run of test fish. By the time these various practical problems were solved and personnel became familiar with the new facilities, the migration was over and fish were not available in large enough numbers to carry out valid tests.

The tandem louver results indicated that low deflection success could be raised by installing a secondary set of louvers. However, the secondary line of louvers was not as efficient in guiding as the primary line.

It was concluded after completion of the 1960 tests that at least one more year would be required to examine the deflection of sockeye and coho smolts by louvers. In particular, more attention would have to be given to the bypass. Consequently a full-scale testing program was drawn up to assess the effects of various bypass widths on the guiding efficiency of sockeye and coho salmon smolts. This program was to be accomplished during the natural downstream migration of juvenile salmon from Great Central Lake in the spring of 1961.

The 1961 tests

The 1961 tests were conducted in the Robertson Creek Test Flume from April 13 to June 10 inclusive and a total of 59,390 sockeye smolts and 17,541 coho smolts migrated through the flume during this period. A total of 59 test nights was completed during which the following variables were tested:

1. Bypass width.
2. Bypass acceleration.
3. Approach velocity.
4. Water depth.
5. Artificial light.
6. Bar spacing.

METHODS

A detailed description of the test facilities used in 1961 has been presented earlier in this report. Of major importance is the fact that all the fish migrating down the flume and either entering the bypass or passing through the louvers were counted. Thus over any given period of time, the guiding efficiency could be calculated and expressed as that percentage of the total number of fish passing down the flume which were deflected into the bypass. In practice, this percentage efficiency was calculated on an hourly basis during the nightly migration period.

The hour by hour variation in guiding efficiency was high, even when test conditions remained constant. For this reason, it was necessary to run each test for a complete night. This provided sufficient numbers of fish and also eliminated the time dependent variables that might be associated with the nightly migration period. The sockeye migration started any time from late afternoon to early evening and was usually over by 1:00 a.m. Data were collected over the complete migration period and for each night the percentage of fish successfully deflected was calculated. These percentage efficiencies form the basis of the 1961 analysis.

The test fish were juvenile sockeye salmon migrants, 60 to 90 mm in length, and coho salmon migrants, 80 to 120 mm in length, that originated in the same lake nursery area as those fish for which the louver prototype would be designed.

The fish entered the test flume after travelling approximately one-half mile down Robertson Creek and all fish used in these tests were naturally migrating fish. Thus the number of test nights depended upon the duration of this downstream migration. The experimental program was designed to obtain the highest sockeye guiding efficiency possible, and timed so that those variables that were considered most important were tested during the peak of the juvenile sockeye migration. Because the design and timing of these experiments were for the sockeye smolts and also because numbers of coho smolts were low, the analysis given pertains primarily to sockeye migrants. For the most part, coho smolts behaved in a similar manner and any major difference noted in coho behaviour is discussed.

TABLE 2—Guiding Efficiency of Naturally Migrating Juvenile Sockeye and Coho Salmon, Robertson Creek, 1961.

Test No.	Date	Water Temp. °F.	Light Conditions	Approach Velocity ft./sec.	Bypass Acceleration % of Approach Velocity	Bypass Width Feet	Bar Spacing Inches	TOTAL NUMBER		GUIDING EFFICIENCY PERCENT		Remarks
								Sockeye	Coho	Sockeye	Coho	
1	April 13	—	natural	2.36	134	0.5(new)	2	104	39	90	85	standard test
2	14	—	natural	2.36	134	0.5 "	2	401	43	87	79	standard test
3	15	—	artificial	2.36	134	0.5 "	2	339	19	69	58	
4	16	45	artificial	2.36	134	0.5 "	2	399	26	74	85	
5	17	46	natural	2.36	110	0.5 "	2	493	74	83	78	
6	18	45	artificial	2.36	110	0.5 "	2	715	82	69	59	
7	19	45	natural	2.36	110	0.5 "	2	588	76	82	94	
8	20	45	natural	3.39	122	0.5(old)	2	283	28	91	80	
9	21	44	artificial	2.39	122	0.5 "	2	293	39	77	87	
10	22	45	artificial	3.76	106	0.5 "	2	1044	84	72	79	
11	23	45	natural	3.76	106	0.5 "	2	676	57	70	84	
12	24	46	artificial	2.36	127	0.5(new)	2	540	40	70	58	
13	25	—	natural	2.36	127	0.5 "	2	1717	89	77	91	standard test
14	26	48	natural	1.49	138	0.5 "	2	1140	131	72	89	
15	27	49	natural	1.49	138	0.5 "	2	1206	83	67	90	
16	28	49	natural	3.57	146	0.5 "	2	1801	129	77	81	
17	29	49	natural	3.57	146	0.5 "	2	3358	551	75	86	
18	30	49	natural	3.58	126	0.5 "	2	2838	534	67	82	
19	May 1	49	natural	3.57	98	0.5 "	2	751	388	59	78	
20	2	49	artificial	2.39	128	0.5 "	2	2644	89	63	83	
21	3	50	natural	2.39	128	0.5 "	2	483	360	78	93	standard test
22	4	51	natural	2.51	124	4.0 "	2	1488	238	97	95	
23	5	51	natural	2.51	124	4.0 "	2	1792	269	99	96	
24	6	51	natural	2.51	124	4.0 "	4	2350	218	100	96	
25	7	52	natural	2.51	124	4.0 "	6	2098	827	100	98	
26	8	51	natural	2.51	121	2.0 "	2	577	701	99	96	
27	9	51	natural	2.51	121	2.0 "	2	753	265	98	96	
28	10	51	artificial	2.49	120	1.0 "	2	1469	215	86	71	
29	11	51	natural	2.49	120	1.0 "	2	1902	345	91	94	
30	12	51	natural	2.49	120	1.0 "	2	487	332	93	95	

TABLE 2—Guiding Efficiency of Naturally Migrating Juvenile Sockeye and Coho Salmon, Robertson Creek, 1961.—Concluded

Test No.	Date	Water Temp. °F.	Light Conditions	Approach Velocity ft./sec.	Bypass Acceleration % of Approach Velocity	Bypass Width Feet	Bar Spacing Inches	TOTAL NUMBER		GUIDING EFFICIENCY PERCENT		Remarks
								Sockeye	Coho	Sockeye	Coho	
31	13	51	natural	2.36	129	0.5 "	2	244	174	92	87	standard test
32	14	52	natural	2.32	140	0.5 "	2	976	332	87	89	standard test
33	15	53	natural	2.36	138	0.5 "	2	2122	249	86	92	standard test
34	16	55	natural	3.60	123	1.0 "	2	4973	890	92	79	
35	17	59	natural	3.80	136	1.0 "	2	3828	726	94	88	
36	18	61	natural	1.31	137	1.0 "	2	1348	689	95	94	
37	19	63	natural	1.31	140	1.0 "	2	1256	450	95	92	
38	20	63	natural	2.79	139	1.0 "	2	1234	910	95	97	
39	21	61	natural	2.79	116	1.0 "	2	909	402	92	96	
40	22	59	natural	2.82	138	1.0 "	4	613	507	92	94	
41	23	59	natural	2.82	111	1.0 "	4	341	287	83	94	
42	24	57	natural	3.07	100	1.0 "	-	401	286	1	1	control test
43	25	57	natural	3.07	100	1.0 "	-	273	190	1	1	control test
44	26	57	natural	2.35	131	0.5 "	2	381	413	81	94	standard test
45	27	57	natural	2.35	131	0.5 "	2	420	344	76	94	standard test
46	28	61	natural	2.35	131	0.5 "	2	373	351	75	93	standard test
47	29	59	natural	2.38	141	1.0 "	4	581	402	91	94	standard test
48	30	60	natural	2.38	144	1.0 "	4 & 2	694	505	93	94	
49	31	62	natural	2.38	144	1.0 "	4 & 2	572	351	93	94	
50	June	63	artificial ¹	2.38	141	1.0 "	4	810	284	72	69	
51		2	artificial ¹	2.38	141	1.0 "	4	500	381	69	71	
52		66	natural	2.43	138	1.0 "	6	505	321	91	94	
53		63	natural	2.43	138	1.0 "	6	398	236	92	93	
54	5	61	natural	1.54	145	1.0 "	2	206	172	95	95	
55	6	60	natural	1.45	125	1.0 "	2	139	122	90	95	depth increased
56	7	58	natural	1.44	132	1.0 "	2	177	168	89	99	depth increased
57	8	59	natural	2.17	131	1.0 "	2	153	343	89	96	depth increased
58	9	59	natural	2.32	134	0.5 "	2	130	369	86	97	standard test
59	10	58	natural	2.32	134	0.5 "	2	104	316	87	97	standard test

¹Flume covered over by a light tight covering.

A total of 59 test nights is available for analysis. Twenty-six of these test nights involved tests which were not repeated and therefore represent a single observation of a given experimental condition. The remaining 33 test nights were made up of 15 lots of paired duplicate test nights plus one lot of 3 duplicate test nights. These latter data were analyzed in an analysis of variance treatment and a common standard deviation was calculated. The common standard deviation obtained in this manner was then applied to all 59 test nights.

Visual observations of juvenile salmon behaviour in the flume were noted and transcribed on a portable disc recorder. These observations were made on specific nights and considerable care was taken not to alarm the fish. Observations were made from various positions on the flume walkway as well as from the observation room.

One test designated as the standard test was repeated approximately every two weeks to test the uniformity of behaviour during the course of the downstream migration. The test conditions were maintained as constant as possible from night to night throughout the 12 standard test nights, so that any changes occurring over this period could not be attributed to changes in the test conditions.

In general all experiments were conducted under as controlled conditions as possible. Personnel conducting the tests remained off the flume except for brief, routine inspection trips or when visual observations were being made. Conditions were such that all counting and sorting of fish was carried out in a light-proof shelter completely removed from the louver array. Although debris was not a problem, the louver array was cleaned each night before testing commenced.

The water depth in the flume during the course of these experiments was kept as constant as possible and varied between 3.5 and 3.8 feet, except during those tests which explored the effect of depth differences.

RESULTS

The physical conditions for the respective tests and the resulting guiding efficiency of the louvers on sockeye and coho smolts for the 59 tests conducted in 1961 are shown in Table 2.

1. Effects of artificial light on guiding efficiency.

Previous work at the Tracy louvers indicated that guiding efficiency of small striped bass and chinook salmon smolts was higher during the night than during the day (Bates et al., 1960). Similar results were obtained during the Puntledge tests with chinook fry. Results from some of the 1960 Robertson Creek tests suggested that illuminated louvers during periods of darkness gave higher guiding efficiencies with sockeye smolts than non-illuminated louvers. In the 1961 tests the effect of overhead illumination on sockeye guiding success was tested on six different occasions. The results of these tests have been extracted from Table 2 and are presented below:

Test number	PERCENT GUIDING EFFICIENCY		
	Natural light	Lighted louvers	Difference
2 and 3.....	87	69	minus 18
1 and 4.....	90	74	" 16
5, 6 and 7.....	83	69	" 14
	82		
12 and 13.....	77	70	" 7
20 and 21.....	78	63	" 15
28 and 29.....	91	86	" 5
Means.....	84	72	minus 12

These data show a reduction in sockeye guiding efficiency when the test flume was illuminated during the regular nighttime migration. The tests encompass a wide range of conditions and it will be noted that in every case a reduction in guiding efficiency took place. To further test the effect of light on sockeye guiding, two test nights were run with the experimental flume covered with a black, light-tight covering. These tests were run using a 12-inch-wide bypass and resulted in the lowering of the nightly efficiency from a range of 91 to 92 percent, to a range of 69 to 72 percent.

Since artificial light conditions proved so important in lowering the guiding efficiencies during the test nights, the hourly efficiencies were examined to see if some relationship existed between natural light intensity and sockeye guiding success. No such relationship could be demonstrated for the migration of smolts during any single night. However, examination of the standard test data did indicate that natural light may have affected the guiding efficiencies throughout the season. This is discussed in detail in a following section.

It was concluded that either introduction of artificial light or complete exclusion of natural light could reduce guiding efficiency of a louver installation such as was tested, by a factor of from 10 to 20 percent. There are no observations which might explain the actual behaviour response involved, but it is suggested that the fish may be unable to adapt themselves to a sudden change in light conditions when they enter the test flume and hence react less positively to the louver array when lighting conditions are extreme than when the test flume illumination is the same as that of the stream. In any case, these results indicate that vision plays an important part in the response of sockeye smolts to louvers.

2. Effects of bypass width on guiding efficiency.

Visual observations during the 1960 louver tests indicated a reluctance for the juvenile sockeye and coho salmon to enter the 6-inch bypass. Schools of both sockeye and coho salmon were seen to disperse in the vicinity of the bypass. A few fish would successfully deflect into the bypass while others darted through the louvers in the immediate vicinity of the bypass. The remaining individuals returned upstream and would repeat the procedure several times during the test period. These observations were verified during the early 1961 tests and are

discussed in more detail below. Bates and Vinsonhaler (*loc. cit.*) mentioned that wild steelhead trout 37 to 44 mm in length showed a reluctance to enter a 6-inch-wide bypass used in the experimental louver installation at Tracy, California. When the width of the bypass was increased to 18 inches the guiding efficiency for these young trout improved. Brett and Alderdice (1958) discuss in some detail the problems associated with getting sockeye and coho salmon smolts to move into a confined opening in connection with their guiding experiments with a hanging cable.

In the present study, the most significant increase in guiding efficiency occurred when the bypass width was increased from its original 6-inch-wide opening to a 48-inch-wide opening (see Tests 21 through 25, Table II). In all, a total of 13 tests on different bypass widths are available for analysis. These data are shown graphically in Figure 21. The results show that the guiding efficiency increases rapidly when the bypass width is increased from 6 inches to 24 inches. A further increase in bypass width does not significantly increase the guiding efficiency.

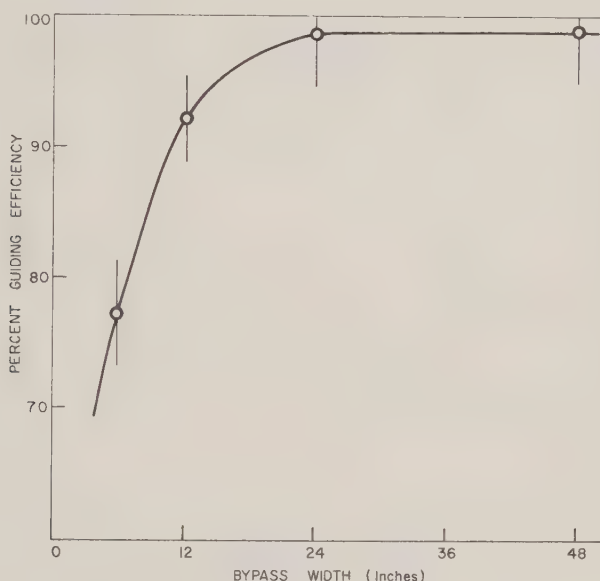


FIGURE 21. *Bypass width and sockeye smolt guiding efficiency, Robertson Creek, 1961. The bar length represents plus and minus two standard deviations.*

It is evident that with schooling sockeye salmon smolts, the width of the bypass is a critical factor. Even quite small schools of a dozen or so fish would not pass, intact, down the 6-inch bypass. It is probable that the effective bypass width is related to the size of the school of fish being deflected. In these tests the largest school noted during this period was in the order of 100 fish. It could prove important at some louver installations to consider means of breaking up large schools of fish prior to their final guiding into a bypass. In any case the observations on bypass width point out the necessity of providing unimpeded entry to the bypass so that upstream return of the migrants does not occur.

3. Effects of bypass acceleration on guiding efficiency.

Bates et al. (loc. cit.) found that the guiding efficiency of chinook salmon smolts increased slightly when the bypass acceleration (expressed as percent of the mean approach velocity), was increased from 120 to 140 percent. They obtained similar results with striped bass under 1.5 inches long. The 1960 tests at Robertson Creek confirmed that an increase in bypass acceleration resulted in a corresponding increase in the guiding efficiencies of sockeye salmon smolts.

In 1961 the effects of bypass acceleration were examined in Tests 16, 17, 18 and 19 (Table II). These tests were conducted with a 6-inch bypass. If the assumption is made that approach velocity has no effect on guiding efficiency with the 12-inch bypass, an additional eight test nights are available for analysis. This assumption seems justified in the light of the experiments on approach velocity (see the following section). Both sets of these data are shown graphically in Figure 22.

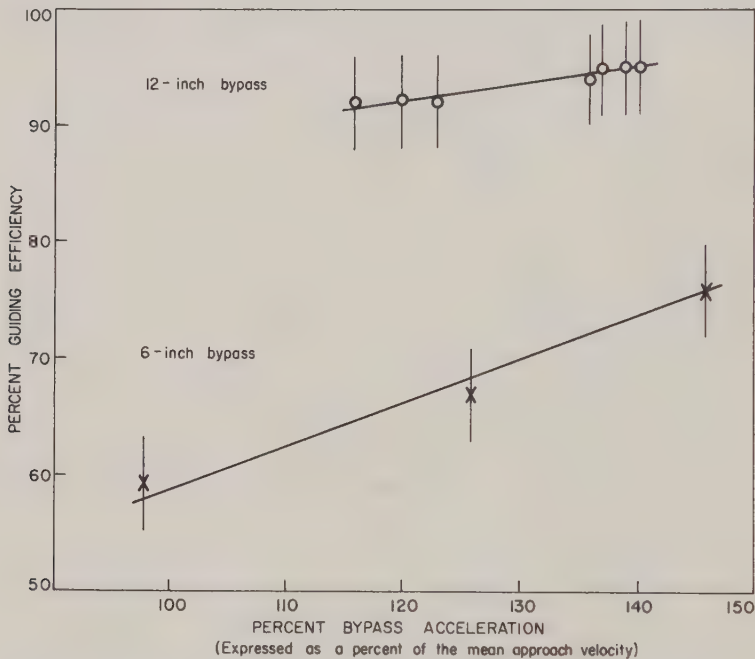


FIGURE 22. Bypass acceleration and sockeye smolt guiding efficiency, Robertson Creek, 1961. The bar length represents plus and minus two standard deviations.

The data obtained from tests run with the 6-inch-wide bypass show almost a straight line relationship between sockeye guiding efficiency and bypass acceleration over the range of accelerations tested. While higher guiding efficiencies were obtained with a 12-inch bypass regardless of bypass acceleration, a similar trend towards increased efficiency was indicated when the bypass acceleration was increased. Results of bypass acceleration tests conducted with the 12-inch bypass were not as striking as those obtained with the 6-inch bypass. It is apparent that the effects of changing the bypass acceleration are lessened if the bypass width is adequate.

Considering these data, some increase in velocity in the bypass seems desirable. On the basis of the data available, a bypass velocity of at least 140 percent of the mean approach velocity seems advantageous.

Bypass acceleration seems to aid in sweeping the fish into the bypass and thus reduces the number of fish back-tracking up the flume and being re-guided to the bypass entrance. Obviously, if a large percentage of the migrating fish must be re-guided several times, a loss in the overall guiding efficiency would ensue.

4. *Effects of approach velocity on guiding efficiency.*

Bates et al. (loc. cit.) present data on chinook salmon smolts that show very little change in guiding efficiencies when the approach velocity varied between 2.0 and 3.3 feet per second. However, at approach velocities of 1.0 and 1.5 feet per second a reduction in the guiding efficiency took place. Data presented by Bates and Jewett (1961) show no effect on guiding efficiency of louvers on young steelhead migrants when the approach velocity was varied between 1.3 and 3.6 feet per second. In experiments conducted on the Puntledge River with chinook fry no consistent effect on guiding efficiency could be shown when the approach velocity was varied between 1.8 and 3.6 feet per second.

In the 1961 tests, the effect of varying the mean approach velocity on the sockeye guiding efficiency was examined in nine test nights. Five of these test

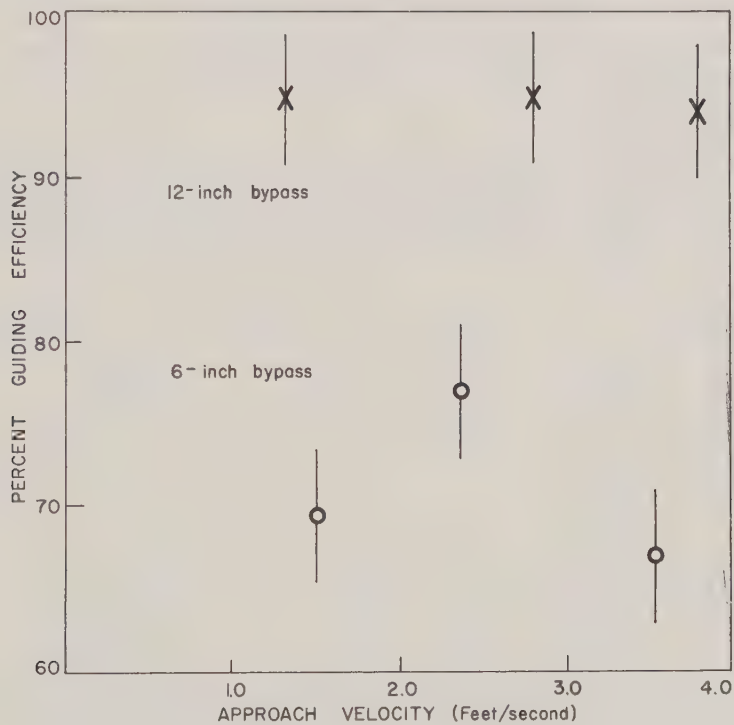


FIGURE 23. Approach velocity and sockeye smolt guiding efficiency, Robertson Creek, 1961. The bar length indicates plus and minus two standard deviations.

nights were made with the 6-inch bypass with velocities of 1.5, 2.4 and 3.6 feet per second. The four remaining test nights were run using the 12-inch bypass and tested velocities of 1.3, 2.8, and 3.8 feet per second. All nine test nights are plotted in Figure 23.

With the 12-inch bypass, a change in the mean approach velocity had no measurable effect on the guiding efficiency. On the other hand, data from tests run with 6-inch bypass show that maximum efficiencies were obtained at an approach velocity of 2.4 feet per second.

These data suggest that if an adequate bypass is provided, a change in the approach velocity over the range tested will not affect the sockeye guiding efficiency of a similarly constructed louver array. These findings agree with the Puntledge results and with results so far reported by other workers on louver tests. However, if for some reason the bypass is not acceptable, best guiding efficiency might be obtained at some optimum approach velocity.

5. *Effects of bar spacing on guiding efficiency.*

Since one of the major problems confronting a louver installation is the trash problem, it is desirable to have the louver bars spaced as far apart as possible. This enables much of the smaller debris to pass through while the larger material can be removed at an upstream trash rack. Although the original experimental design did not call for the testing of bar spacing, once the high efficiencies were obtained by altering the bypass width, it became worthwhile to examine the possibility of increasing the bar spacing.

As demonstrated in Tests 22 through 25 (Table 2), which were run with the 48-inch bypass, bar spacings of 2 inches, 4 inches and 6 inches all produced similar guiding efficiencies.

With the introduction of the bypass problem, however, an advantage was gained with smaller bar spacing. Using data from the 12-inch-wide bypass tests, a small loss of efficiency was noted when the bar spacing was over two inches. A total of nine test nights is available for analysis and these have been extracted from Table 2 as follows:

Test numbers	Bar spacing	Percentage efficiency
35	2"	94
36	2"	95
37	2"	95
38	2"	95
54	2"	95
40	4"	92
47	4"	91
52	6"	91
53	6"	92

It is interesting to note in the above data that no loss in guiding efficiency was shown when the bar spacing was increased from 4 inches to 6 inches. It

seems that if an adequate bypass could be designed for passing schooling sockeye smolts, a much more open louver array could be installed than was formerly thought feasible. Further testing on this variable should prove fruitful in connection with schooling species such as sockeye salmon smolts.

6. Effect of depth on guiding efficiency.

As outlined earlier all but three tests were run at a depth varying between 3.5 and 3.8 feet. These three exceptions were provided to test the effect of depth on guiding efficiency. Unfortunately the greater the depth in the flume, the more dead water area was created ahead of the downstream stoplogs and this provided a resting area a short distance within the bypass. The fish migrating during these tests did considerable back-tracking and most were deflected several times before eventually being swept over the stoplogs. For this reason the five percent drop in efficiency (see Tests 55, 56 and 57), should not be attributed wholly to the increase in depth. Further testing as to the effects of depth on the guiding efficiency of louvers should be conducted.

7. General behaviour of juvenile sockeye migrants during deflection.

Although visual observations were not stressed in the 1961 louver guiding tests, such observations were made on several occasions with the realization that some insight might be gained on the behaviour responses involved in louver deflection. The discussion in this section will be limited to sockeye behaviour, and that of the juvenile coho smolts will be discussed later.

Schools of sockeye juveniles were observed to react differently to varying flume velocities. At slow velocities of about 1.3 feet per second, most of the fish entered the flume swimming downstream headfirst. Many of these individuals continued to do so until they either swam into the bypass, if the bypass was acceptable, or became excited and swam upstream again if the bypass was not acceptable. With this low velocity many individuals swam out of the bypass and had to be deflected many times before eventually passing over the downstream stoplogs onto the inclined-plane trap.

At intermediate velocities of about 2.5 feet per second, juvenile sockeye smolts appeared to be transported passively downstream. Although the individuals of a school maintained their position relative to one another, the direction in which they were orientated with regard to the current appeared to be chance. Following reaction to the louvers most of the fish orientated themselves with heads facing upstream. As the current continued to carry the intact school downstream, the group avoided the louvers by slight, lateral, darting movements. Almost all fish at this velocity entered the bypass tailfirst.

At velocities of 3.8 feet per second, sockeye smolts were carried downstream tailfirst and entered the flume oriented head upstream. Following reaction to the louvers, most of these fish would orientate with their tails towards the louvers and be swept into the bypass in this position.

Sockeye behaviour changed noticeably when the bypass width was increased from six inches to a width of at least 12 inches. Observations made on test nights when the 6-inch bypass was in operation showed quite clearly that sockeye smolts, especially when schooled were reluctant to enter the bypass.

The fish would deflect normally from the louver array, usually orientating themselves along the wall opposite the louvers. As they proceeded downstream, the wall and the louver array grew closer together and when the fish were within one or two feet of the louvers, they began to sound gradually to the floor of the flume. In the case of lone individuals, these fish would often hold just ahead of the bypass entrance. They would then either be swept down the bypass or swim varying distances up the flume to be guided over again. In the case of schools, an elongation in the shape of the school occurred with some of the members extending into the bypass. Some of these individuals were swept down the bypass, while others darted upstream startling the whole school into an upstream migration. These fish would then hold at various locations along the edge of the flume opposite the louver bars and as the night progressed, this group of fish increased until it occupied a large area strung out all along the wall opposite the louvers. The number of times this general behaviour pattern was repeated in a night depended partially on the approach velocity, but in any case a decided reluctance to enter the 6-inch bypass resulted in a corresponding decrease in the nightly guiding efficiency.

With a 12-inch-wide bypass, fish were observed deflecting readily into the bypass and no large concentration of fish accumulated in the flume during the course of the nightly migration. The downstream migrants did not sound in the vicinity of the bypass as they typically did when confronted with a 6-inch bypass. Some large schools estimated at about 100 individuals, did elongate as they approached the 12-inch bypass. These schools, however, entered the bypass intact and only a few individuals were observed back-tracking from the bypass entrance.

8. Changes in guiding efficiency during springtime migration.

As mentioned earlier, one test designated as the standard test, was repeated approximately every two weeks to test the uniformity of behaviour during the course of the year's tests. This test was conducted with a 6-inch bypass and test conditions from night to night were maintained as constant as possible with the approach velocity ranging between 2.3 and 2.4 feet per second and the bypass acceleration ranging between 127 and 140 percent.

Despite the uniformity of the test conditions, a significant variation in the guiding efficiency was noted. Various factors were examined such as water temperature, size and behaviour of schools, timing of the downstream migration and prevailing weather conditions, in an effort to explain this variation. None of these factors was adequate to explain the variations found.

Since gross changes in the lighting had a decided effect on the guiding efficiency, the available hourly lighting readings were examined for the nights on which standard tests had been run. Light readings were taken only once every hour and reflect the light conditions at the moment of determination only. In any case, some indication was obtained that on relatively dark nights the standard test efficiency was higher than on relatively bright nights. In Figure 24, the sockeye guiding efficiencies obtained from the various standard tests are plotted along with the moon phase.

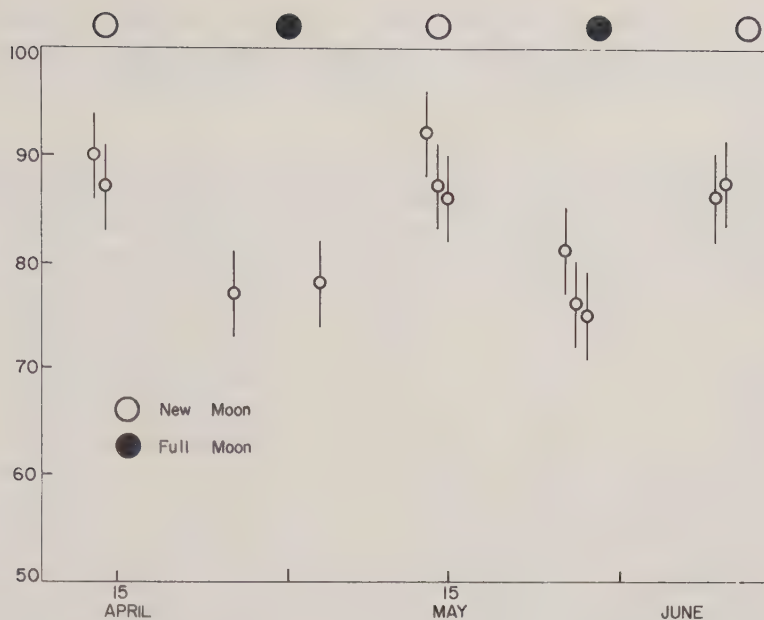


FIGURE 24. Sockeye smolt guiding efficiency during standard test nights, Robertson Creek, 1961. The time of occurrence of new and full moons is shown along the top of the graph. The bar length represents plus and minus two standard deviations.

A cyclic change in the sockeye guiding efficiencies corresponding to the phase of the moon is evident in examining the relationship. Periods when a new moon prevailed corresponded to high sockeye guiding efficiencies and periods of full moon corresponded to low efficiencies. In any case, a gross change in the sockeye guiding efficiency occurred during the course of the experiments. In the light of these observations all experimental data were re-examined to determine if any of the previous conclusions were a result of a basic change in guiding efficiency due to natural causes rather than experimental conditions. Since most of the specific relationships were tested over a relatively brief period, it is unlikely that this rather long-term effect would influence the results. The period when the maximum guiding efficiency was attained with the wide bypasses occurred when the standard tests indicated a period of low guiding efficiency, and therefore the original conclusion on the importance of bypass width is strengthened.

9. Guiding efficiency of coho salmon smolts.

In general, coho smolts responded to the louvers and were deflected with much the same success under the various conditions tested as were sockeye smolts. The coho juveniles did not show as much reluctance to enter the 6-inch bypass as did sockeye and the efficiencies were correspondingly higher under these conditions. Conversely, the average coho guiding efficiencies were never as high as the corresponding sockeye efficiencies when wide bypasses were used. Perhaps had the coho been migrating in large schools, this difference in guiding

efficiencies would lessen. A greater percent of daytime migration occurred with coho than with sockeye smolts and these daytime guiding efficiencies tended to be from 4 to 5 percent higher than the nighttime guiding efficiencies.

DISCUSSION

The results of the 1961 tests suggest that a louver installation could be a practical solution to the problem of screening sockeye and coho salmon smolts from the proposed Stamp River power canal. It was demonstrated that the louver principle worked with up to 99 percent guiding efficiency for sockeye smolts and better than 96 percent efficiency with coho smolts. The data points out quite clearly the importance of providing an adequate bypass, and only if this is done will the full guiding potential of a louver array be realized. Such variables as bar spacing, approach velocity, and bypass acceleration lose much of their effect on the guiding efficiency when a bypass of adequate width is provided. Although the data show bypass width to be the most important single variable, it may be possible to design an acceptable bypass of relatively narrow width after research on various types of bypasses has been conducted.

It was concluded on the basis of the results obtained during the 1961 tests that the following factors should be considered in the design of the louver installation at the proposed Stamp River power intake: the louver array should be illuminated by natural light only; all unnatural light sources should be eliminated, especially in the vicinity of the bypass; the velocity in the power canal should not exceed 4 feet per second; the velocity in the bypass should exceed the approach velocity in the power canal over all ranges of approach velocity (this acceleration in velocity should be in the order of 140 percent of the mean approach velocity); the bypass width should be at least 18 inches and the design should call for 2-inch bar spacings with provisions for testing the effects of increasing the spacing along part or all of the louver array.

The 1962 tests

The proposals for louver installations at both the Puntledge and Stamp River power canals included consideration of a Vee-arrangement of the louver line. The advantage gained by this type of installation over a straight-line arrangement is greater compactness and therefore lower initial cost. An additional advantage would be gained if both banks of louvers forming the Vee shared a common bypass. This would reduce the amount of fish bypass water required and thus increase the amount of water available for power generation. Since adequate tests on the Vee-arrangement had not been carried out in any previous evaluation of louvers, a decision was made to test this type of louver apparatus in the Robertson Creek Test Flume during the 1962 downstream migration of juvenile salmon.

Besides coho and sockeye smolts migrating from Great Central Lake, large numbers of chinook and coho fry were available for testing in 1962. These fry were the progeny of chinook and coho salmon which spawned in Robertson Creek in the fall of 1961. The availability of chinook fry enabled guiding data to be gathered on this species additional to that obtained during the Puntledge

louver tests. Guiding data on coho fry would provide the basis for comparison of this more or less passively migrating species with the guiding results obtained for the other species mentioned, all of which are actively migrating directly to sea.

Tests were conducted in the Robertson Creek experimental flume from April 16 to June 3 inclusive. This period covered the major portion of the downstream migration of smolts and fry from Great Central Lake and Robertson Creek. A total of 44 test nights was completed during which the following variables were tested:

1. Bypass width.
2. Bypass acceleration.
3. Approach velocity.
4. Center wall position.

METHODS

Details of the 1962 facilities have already been described and are shown in Figure 20. Once again it should be noted that all the fish migrating down the flume and either entering the bypass or passing through the louvers were counted. The percentages of fish from a total night's migration that were found in the bypass trap are the basic data used in the following analysis. In general procedures were similar to those of the 1961 tests.

Each test started at 5:00 p.m. and ended the following morning at 8:00 a.m. This period encompassed almost all of the total daily migration. Fish were counted individually by species each hour during the main migration period which lasted from dusk to one or two a.m. During the day necessary changes were made on the test facilities in preparation for the next night's testing. The nightly guiding efficiencies of each species were analyzed in an analysis of variance treatment and a common standard deviation for each species was calculated.

One series of tests in 1962 was designed to test the necessity of a center wall running down the middle of the Vee formed by the converging louver lines. This center wall was tested in two positions. In one of the positions, it extended approximately eight feet into the bypass and therefore formed a situation comparable to a single line of louvers ending in a separate bypass. In the second position, the downstream end of the center wall was outside the mouth of the bypass. The exact position was such that the perpendicular distance from the downstream end of the center wall to the louver array on either side, was exactly equal to the bypass width. This position was the farthest position the wall could extend downstream without decreasing the effective width of the shared bypass. This is referred to as the "equilateral" position.

RESULTS

During the tests, 91,600 sockeye smolts, 20,100 coho smolts, 86,200 coho fry and 76,000 chinook fry were counted as they passed through the Robertson Creek experimental flume. These were the test fish on which the evaluation of the Vee-louver arrangement was based. A total of 41 test nights was available for examination, and the results of these are summarized in Tables 3 and 4.

TABLE 3—Nightly Guiding Efficiency of Vee-Louvers, Robertson Creek, 1962.

Test No.	Date	Approach Velocity	Bypass Acceleration	Bypass Width Inches	Center Wall Position	NUMBERS				PERCENT GUIDING EFFICIENCY			
						Sockeye Smolts	Coho Smolts	Coho Fry	Chinook Fry	Sockeye Smolts	Coho Smolts	Coho Fry	Chinook Fry
1	Apr. 24	2.6	109%	24	out	1684	183	5113	3974	96	97	32	53
2	25	2.6	109%	24	out	2172	153	3225	3243	96	97	29	66
3	26	2.6	128%	16	out	2205	228	5299	4523	96	94	29	72
4	27	2.6	127%	16	out	2509	240	2260	1602	96	96	27	56
5	28	2.6	101%	16	out	3145	227	2554	1354	92	88	21	67
6	29	2.6	99%	16	out	3032	510	3826	1266	91	85	18	68
7	30	2.5	134%	12	out	1043	320	3676	2174	94	87	36	63
8	May 1	2.5	134%	12	out	1753	520	2756	2650	94	86	24	71
9	2	3.4	134%	12	out	2357	326	4002	12429	93	89	27	70
10	3	3.4	134%	12	out	3236	306	2304	3359	92	85	29	69
11	4	1.6	130%	12	out	1885	266	2388	3367	82	89	24	52
12	5	1.6	130%	12	out	3629	306	2949	4432	79	85	22	53
13*	6	1.6	130%	12	out	1287	426	221	543	87	90	9	15
14	7	2.7	100%	12	out	4536	228	4524	8880	86	85	25	65
15	8	2.7	100%	12	out	5593	256	4690	5718	84	79	19	61
16	9	2.9	145%	12	out	3579	403	4584	5001	91	84	15	65
17	10	2.9	145%	12	out	1649	550	3294	3351	92	88	19	65
18	11	2.6	136%	12	1	682	341	1805	1170	92	89	26	76
19	12	2.6	136%	12	1	1841	452	1388	1041	91	88	27	77
20	13	2.6	135%	2 x 6	2	1434	329	685	312	93	93	25	73
21	14	2.6	135%	2 x 6	2	3981	431	401	341	93	95	30	64
22	15	2.6	136%	6	out	9077	723	470	269	80	81	19	58
23	16	2.6	136%	6	out	4390	436	299	127	80	88	16	45

*This test was conducted with artificial lighting illuminating the test area.

1. Center wall in the "equilateral" position (see text for explanation).

2. Center wall extending approximately 8 feet into the bypass.

TABLE 4—Nightly Guiding Efficiency with Single Louver Line, Robertson Creek, 1962.

Test No.	Date	Approach Velocity Ft./Sec.	Bypass Acceleration	Bypass Width Inches	NUMBERS				PERCENT GUIDING EFFICIENCY			
					Sockeye Smolts	Coho Smolts	Coho Fry	Chinook Fry	Sockeye Smolts	Coho Smolts	Coho Fry	Chinook Fry
24	May 17	2.6	133%	6	2183	484	340	85	78	96	19	58
25		2.6	133%	6	3085	892	249	190	75	96	20	53
26		2.6	133%	6	3009	1339	448	350	76	96	17	61
27		2.6	133%	6	2414	1253	1074	580	75	96	22	71
28	21	2.6	198%	6	2711	793	4279	1031	90	98	39	84
29		2.6	198%	6	1740	361	1634	370	93	98	39	87
30	23	2.6	167%	6	1641	820	1619	345	90	97	43	86
31		2.6	167%	6	1416	995	1545	456	92	98	40	86
32	25	2.6	147%	6	1480	559	1438	267	89	97	41	87
33		2.6	147%	6	1313	647	1570	244	90	98	45	87
34	27	2.6	132%	6	814	611	2962	397	85	98	51	88
35		2.6	132%	6	277	419	1269	141	89	97	51	88
36		2.6	132%	6	527	554	700	166	83	93	38	86
37		2.6	132%	6	404	465	1112	68	92	95	42	81
38	31	2.5	99%	6	413	505	983	34	0.5	0	12	3
39		2.5	99%	6	258	395	914	71	1.2	0	7	1
40	2	2.6	100%	6	385	499	318	19	1.0	0	15	1
41		2.6	100%	6	246	314	481	59	0.5	0	9	2

The sockeye smolts had a mean length of 70 mm, the coho smolts 95 mm, the coho fry 34 mm, and the chinook fry 42 mm.

1. *Effects of bypass width on guiding efficiency.*

a) *Sockeye smolts.*

The 1961 louver tests showed the importance of bypass width when guiding sockeye smolts with a single line louver array. In the 1962 tests, this variable was re-examined utilizing Vee-louvers and a shared center bypass.

Figure 25 (a) illustrates the relationship between bypass width and the guiding efficiency for sockeye smolts with Vee-louvers. It is apparent that the same curvilinear relationship exists as was demonstrated for a single line louver array in 1961. The sockeye efficiency rises rapidly as the bypass width is increased from 6 inches to 12 inches, then begins to level off until no further increase in guiding efficiency occurs with a bypass width greater than 16 inches.

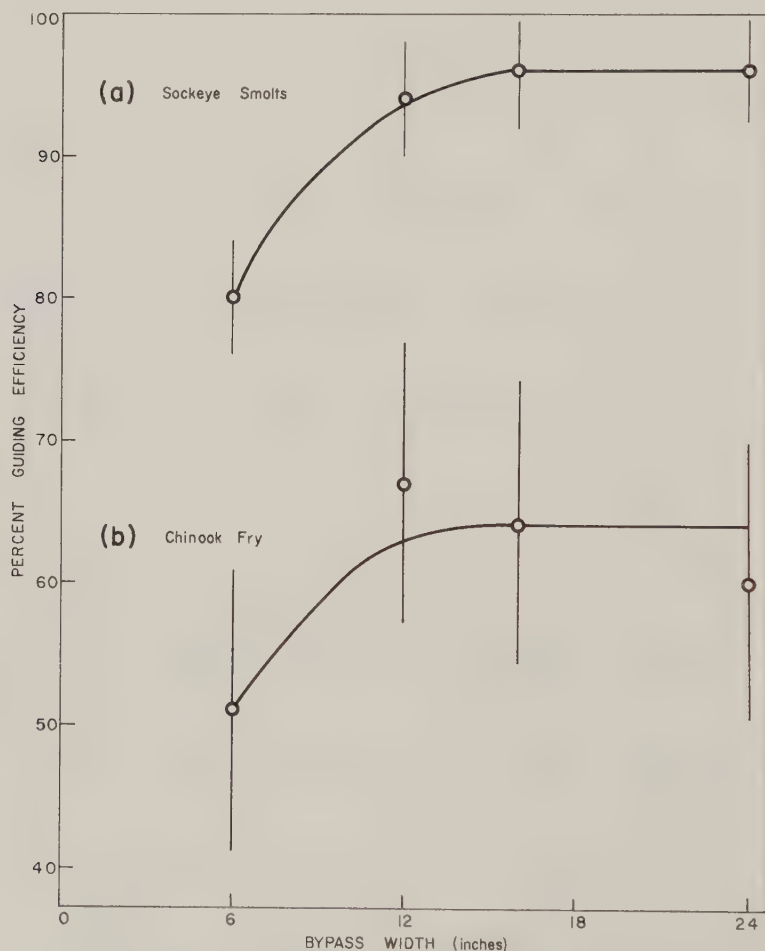


FIGURE 25. *Bypass width and guiding efficiency of sockeye smolts and chinook fry, Robertson Creek, 1962. The bar length represents plus and minus two standard deviations.*

b) *Chinook fry*.

No previous information is available on the effect of bypass width on the efficiency of louvers in deflecting chinook salmon fry. From the data graphed in Figure 25 (b), it appears that a similar relationship exists as was described above for sockeye smolts. In the case of chinook fry, an increase in guiding efficiency again occurred when the bypass width was increased from 6 inches to 12 inches. No further advantage was obtained by increasing the bypass width more than 12 inches.

c) *Coho smolts*.

The data on the effect of bypass width on coho smolt guiding efficiency suggests that the main advantage in increasing the bypass width for these fish occurs within a relatively narrow range. Thus, as depicted in Figure 26 (a), no significant gain in guiding efficiency was achieved by increasing the bypass width from 6 inches to 12 inches, but when the bypass width was increased to 16 inches a substantial increase in guiding efficiency occurred. Widening the bypass to 24 inches did not appear to have altered the guiding efficiency significantly from that obtained with a 16-inch width.

d) *Coho fry*.

The effect of bypass width on coho fry deflection utilizing a Vee-louver arrangement is plotted in Figure 26 (b). The guiding efficiency is very low at all bypass widths. An increase in efficiency is apparent when the bypass was increased from 6 inches to 12 inches, after which an increase in bypass width

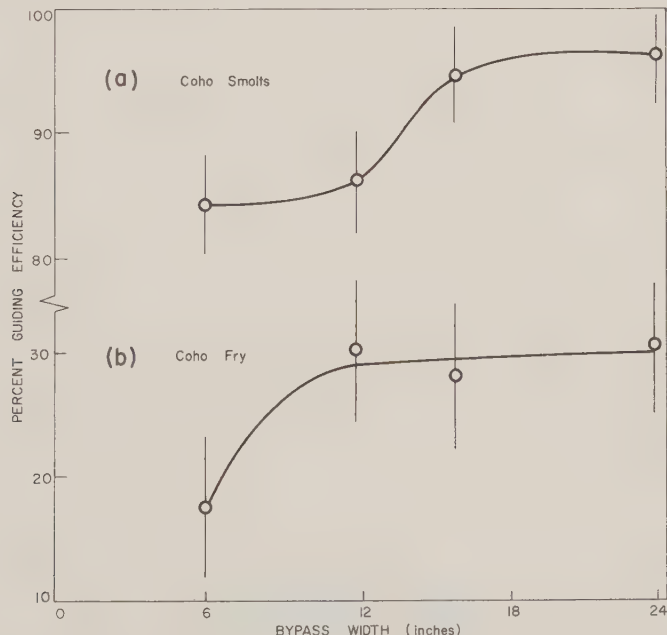


FIGURE 26. Bypass width and guiding efficiency of coho smolts and coho fry, Robertson Creek, 1962. The bar length represents plus and minus two standard deviations.

did not noticeably affect guiding efficiency. Figure 26 demonstrates the tremendous difference in guiding efficiency between coho fry and coho smolts under identical experimental conditions.

2. Effects of bypass acceleration on guiding efficiency.

a) Sockeye smolts.

In the 1961 single line louver tests, higher bypass acceleration produced higher sockeye smolt guiding efficiencies. The increase was more pronounced when the tests were conducted utilizing a 6-inch bypass than when they were conducted with a 12-inch bypass. The present series of tests enables us to examine this relationship with Vee-louvers and a 12-inch-wide bypass.

Figure 27 (a) shows the relationship between sockeye smolt guiding efficiency and bypass acceleration. The guiding efficiency rose significantly when the bypass acceleration rose from 100 percent of the mean approach velocity to 134 percent. No significant increase occurred when the bypass velocity was increased to 145 percent of the mean approach velocity. Information gained in 1961 tests, as well as some observations made in 1962, indicate that guiding efficiency of sockeye smolts increases with bypass accelerations up to about 145 percent of the approach velocity.

b) Chinook fry.

Figure 27 (b) demonstrates that bypass accelerations within the range of from 100 to 145 percent of the mean approach velocity have little or no effect on chinook salmon fry guiding efficiency with Vee-louvers under the conditions tested.

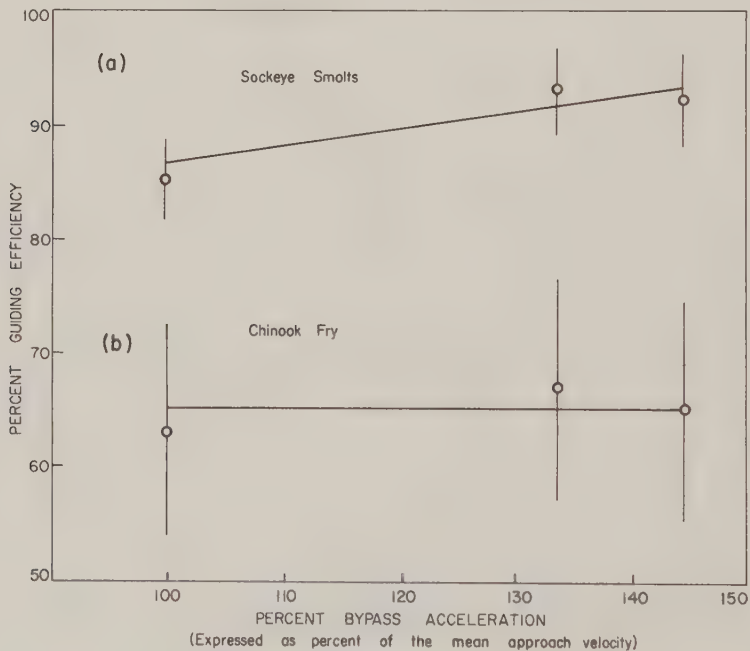


FIGURE 27. Bypass acceleration and guiding efficiency of sockeye smolts and chinook fry, Robertson Creek, 1962, using a 12-inch bypass. The bar length represents plus and minus two standard deviations.

c) *Coho smolts.*

The data obtained on the effect of bypass acceleration on coho smolt deflection are presented in Figure 28 (a). A slight increase in guiding efficiency is suggested from these data when the bypass velocity is accelerated up to 134 percent.

d) *Coho fry.*

In Figure 28 (b) the effect of bypass acceleration on coho fry deflection is plotted. Interpretation of the results of these tests is difficult because of the variability inherent in these data. Two freehand curves have been drawn which could represent trends from these data. One curve, the solid line, suggests that the guiding efficiency increases as the bypass acceleration increases up to a point somewhere between 120 and 130 percent acceleration, after which a sharp reduction in guiding efficiency results with a further increase in bypass acceleration. The broken line curve suggests that little or no increase in efficiency occurs when the bypass acceleration lies between 100 and 135 per cent of the mean approach velocity, but that when the acceleration in the bypass exceeds 135 percent, a sharp reduction in guiding efficiency occurs. In any case, a decrease in coho fry efficiency occurred when the bypass acceleration was increased from 134 percent to 145 percent of the mean approach velocity.

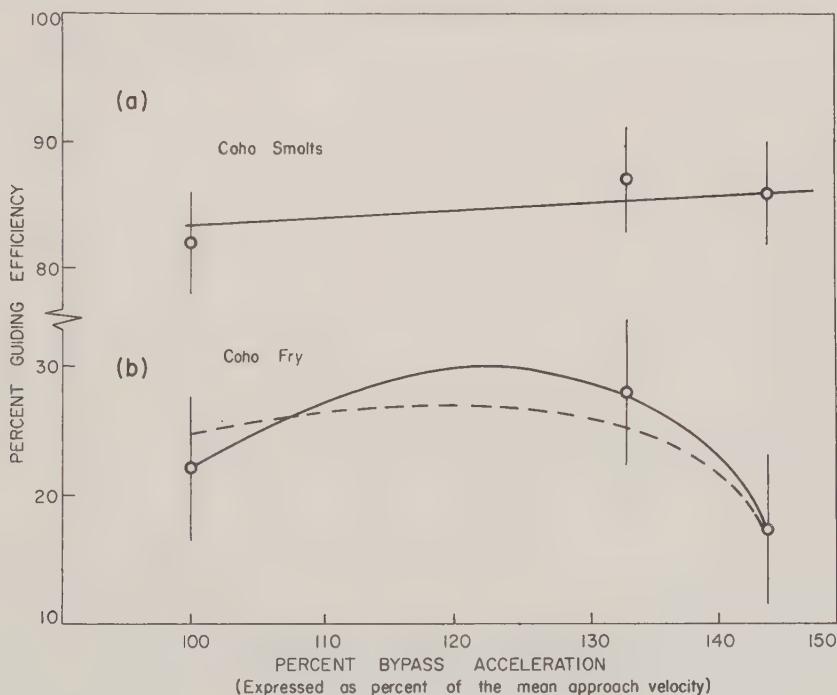


FIGURE 28. Bypass acceleration and guiding efficiency of coho smolts and coho fry, Robertson Creek, 1962, using a 12-inch bypass. The bar length represents plus and minus two standard deviations.

3. Effects of approach velocity on guiding efficiency.

a) Sockeye smolts.

Data from the 1961 tests showed little or no effect when the approach velocity was varied between 1.3 and 3.8 feet per second on sockeye smolt guiding efficiency with a 12-inch-wide bypass. However, when a 6-inch bypass was tested, a maximum guiding efficiency was obtained at approach velocities of approximately 2.4 feet per second.

The guiding efficiency of sockeye smolts in the 1962 Vee-louver tests conducted with a 12-inch bypass are plotted in Figure 29 (a). The guiding efficiency rose rapidly when the approach velocity increased from 1.6 feet per second to 2.5 feet per second. Velocities between 2.5 and 3.4 feet per second produced somewhat lower deflection results.

b) Chinook fry.

The degree of variability in these data makes interpretation difficult, but a relationship seems to exist for chinook fry similar to that described above for sockeye smolts, as shown in Figure 29 (b). The guiding efficiency rose when the approach velocity was increased from 1.5 feet per second to 2.5 feet per second, after which further increases of up to 3.4 feet per second had no measurable

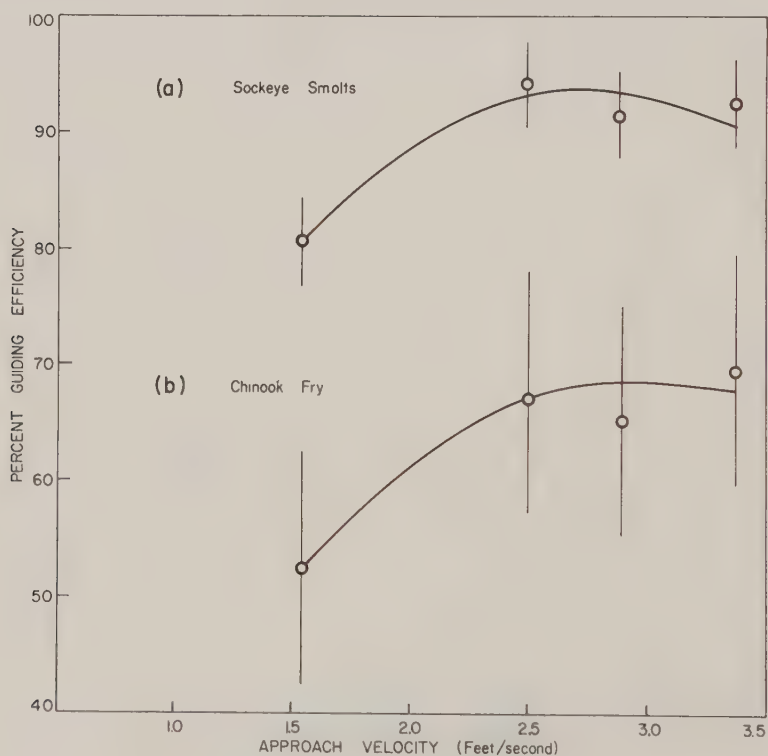


FIGURE 29. Approach velocity and mean guiding efficiency of sockeye smolts and chinook fry, Robertson Creek, 1962, using a 12-inch-wide bypass. The bar length represents plus and minus two standard deviations.

effect. These results strengthen the conclusion made from the Puntledge tests that approach velocities between 1.8 and 3.6 feet per second are acceptable for a louver installation designed to guide chinook fry migrants.

c) *Coho smolts.*

The data on the effect of approach velocity on the guiding success of coho smolts is presented in Figure 30 (a). These data indicate that varying the approach velocity between 1.5 and 3.4 feet per second has no effect on the guiding efficiency of coho smolts utilizing Vee-louvers with a 12-inch bypass.

d) *Coho fry.*

No clear relationship is apparent between approach velocity and the guiding success of coho fry with Vee-louvers and a 12-inch bypass, as shown in Figure 30 (b). Obviously more testing with this species is required before the effect of approach velocity can be evaluated.

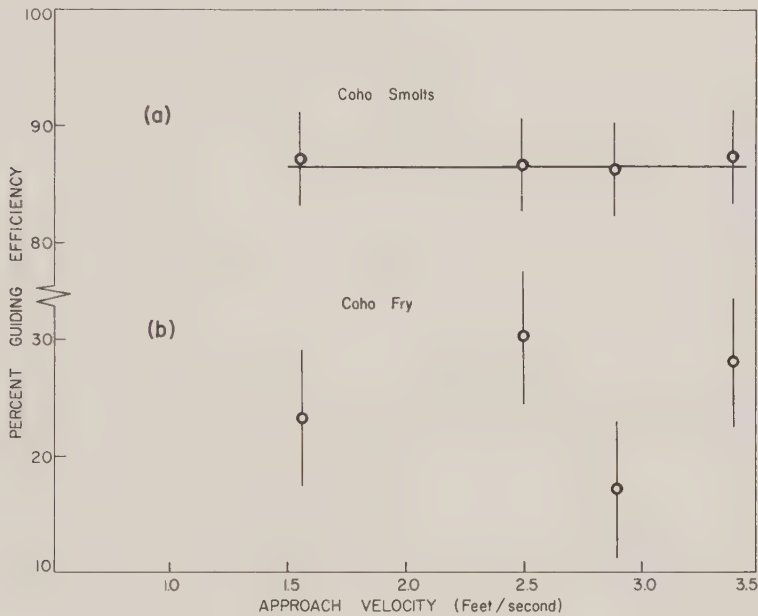


FIGURE 30. Approach velocity and mean guiding efficiency of coho smolts and coho fry, Robertson Creek, 1962, using a 12-inch wide bypass. The bar length represents plus and minus two standard deviations.

4. Effects of a center wall on guiding efficiency.

Because sockeye and coho smolts were known to react strongly to the louvers and orient themselves along the smooth flume wall during the 1961 tests, it was felt that a center wall might increase the guiding efficiency of a Vee-Louver installation. Since bypass width was a critical parameter in the 1961 tests, the most desirable position of the center wall was assumed to be one where the distance from the downstream end of the louvers was equal to the bypass width.

In addition to this "equilateral" position, the center wall was also tested extending into the bypass for a distance of eight feet. A total of 6 test nights is available for analysis: test numbers 7, 8, 18, 19, 20 and 21 (Table 3).

a) Sockeye smolts.

The guiding efficiency of sockeye smolts was not significantly altered by the addition of a center wall in either of the two positions tested.

b) Chinook fry.

A marked increase in the guiding efficiency of chinook fry occurred when the center wall was in the "equilateral" position. The mean guiding efficiency of chinook fry with no center wall and a 12-inch bypass width, under the conditions tested, was 67 percent. Under the same hydraulic conditions, but with the center wall in the "equilateral" position, the efficiency rose to a mean of 76.5 percent. When the wall was extended into the bypass, creating in effect two 6-inch bypasses, the efficiency fell to a mean of 68 percent.

c) Coho smolts.

The center wall in the "equilateral" position did not significantly affect the guiding efficiency of coho smolts. When the center wall was extended into the bypass however, the efficiency rose from a mean of 88 percent to a mean of 94 percent.

d) Coho fry.

No significant effect of the center wall in either position was detected in the coho fry results.

5. Single line louver tests during 1962.

Visual observations during the Vee-louver experiments suggested that coho and chinook fry tended to favor the walls of the flume as they moved downstream. It was felt that if this tendency was exploited a gain in guiding efficiency for these species might be realized. Therefore, a series of tests was run late in the testing schedule using a single 100-foot line of louvers guiding to a bypass situated along one wall. During this series, high bypass acceleration was also tested. A summary of the single line louver tests is given in Table 4.

The migration of the juvenile salmon tested was almost concluded and perhaps the behaviour of this tailend segment of the migrating population is not typical of the major portion. It is difficult to explain, for instance, the difference in the guiding efficiencies of coho and chinook fry during tests 24 to 27 as compared to the efficiencies obtained during tests 34 to 37. Although not conclusive, the results of these single line experiments suggest that perhaps some increase in the guiding efficiency of coho and chinook fry could be realized by guiding towards the banks of any given power intake canal.

The results of the high bypass acceleration tests with the 1962 single line of louvers do not change any of the previous conclusions arising from earlier tests.

DISCUSSION

The 1962 Vee-louver experiments confirmed that this configuration is a practical answer to installing compact louver facilities in power intake canals. In areas, such as the Stamp River, where the species of major concern are sockeye and coho smolts, a Vee-louver arrangement with 18-inch-wide, shared bypasses is considered acceptable. When the species involved is chinook fry, a center wall extending to the "equilateral" position should be added to the Vee configuration.

Results from the 1962 experiments indicate that approach velocity, bypass width and bypass acceleration of a Vee-louver installation affects the guiding efficiencies of sockeye and coho salmon smolts in much the same manner as was determined in experiments with a single line louver array in 1961.

Chinook fry data are not as conclusive as those obtained for sockeye and coho smolts. The common standard deviation for chinook fry guiding efficiencies was 4.9 percent in the 1962 tests while the standard deviations of the sockeye and coho efficiencies were 1.9 and 2.0 percent respectively. This greater variability makes the interpretation of the chinook data difficult and some of the conclusions drawn from these data are in need of strengthening by means of additional tests. However, the results of the 1962 chinook fry guiding tests tend to substantiate those obtained during the Puntledge tests and no change in the conclusions drawn from these earlier tests is warranted. The most important finding in 1962, in so far as chinook fry guiding with Vee-louvers is concerned, was the advantage gained by utilizing a center wall placed in the "equilateral" position.

The guiding success of louvers on coho salmon fry was below what would be acceptable for screening this species from hydro-electric power canals. Coho fry generally spend their first year of life rearing in the stream. Perhaps the fact that coho fry are not actively migrating seaward is a partial answer to the low guiding efficiencies obtained. These fish were also the smallest fish tested and perhaps the efficiency of the test facilities could have been increased by a narrower spacing between the louver bars. In any case, more testing would be required before a decision on the feasibility of the louver principle for guiding coho fry could be made.

HYDRAULIC OBSERVATIONS OF LOUVER APPARATUS AT ROBERTSON CREEK, 1960 AND 1961

Engineers designing a prototype louver installation at the power canal at the Puntledge River intake or at the proposed Stamp River power development would need to know some of the hydraulic characteristics of louvers, particularly the hydraulic head loss to be expected. Hence, in addition to routine velocity and depth measurements, careful hydraulic observations were made during the louver fish guiding efficiency tests conducted at the Robertson Creek Test Flume. As well as observing hydraulic head loss, measurements were taken to determine the velocity distribution in the test flume upstream of the louver line in relation to the observed bypass acceleration, and also to determine the vertical distribution of water velocities at the fish bypass entrance. These special observations are discussed in the sections following.

Head loss through the louver line.

Initially, the head loss through the louver line was determined simply by computing the difference between headwater and tailwater levels. Subsequently, however, a more accurate approach based on the difference between the total hydraulic energy on each side of the louver was employed because seemingly small reductions in the relatively shallow depths of flow employed in the tests caused substantial velocity increases which required consideration.

Head loss represented by total energy differences can be calculated by the formula:

$$\Delta H = \frac{KV^2}{2g}$$

where ΔH = Head loss in feet
K = Loss coefficient
V = Water velocity in ft/sec
g = Acceleration due to gravity
in ft/sec/sec.

"K" in the equation varied from 1.89 for a single louver line in a 10-foot-wide flume to 1.62 for a single line in a 20-foot-wide flume, each leading to one six-inch-wide fish bypass respectively. The fact that "K" did not remain constant was probably due to the changing flume width combined with the fact that a narrow fixed width of the louver at the upstream end is totally blocked to flow. Moreover, the average hydraulic radius for the 10-foot flume width was 2.22 feet as compared with 2.86 feet for the 20-foot-wide structure, a difference which might also affect the magnitude of "K".

The expected head loss in a prototype employing a long line of louvers at 2-inch bar intervals should not be more than $1.62 \frac{V^2}{2g}$ — if the structure is kept free of debris. Values for "K" for bar spacings of 4 inches and 6 inches are not available for narrow fish bypass widths.

Variation of velocity distribution upstream of louvers.

It is generally agreed among workers in the field of fish guiding that all changes in velocity in the flow upstream of a guiding apparatus should be gradual and that the flow into the fish bypass should accelerate gradually. In the Robertson Creek experiments, plots of velocity at various points upstream of, and along the louver line, indicate that the velocity of water entering the bypass must be well in excess of the average approach velocity if these requirements are to be satisfied. Figures 31 and 32 are plots of water velocities measured along the length of the flume at points midway between the louver and the flume wall under two different sets of conditions during the 1961 Robertson Creek louver tests. Figure 31 shows the rate of change of velocity upstream of the fish bypass at three different approach velocities. Figure 32 shows the rate of change of

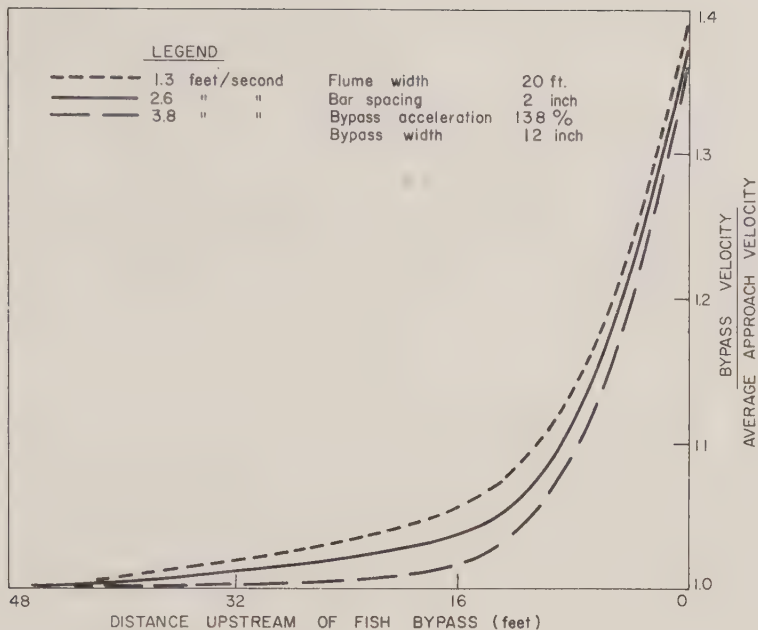


FIGURE 31. Velocity distribution upstream of louvers at three approach velocities, Robertson Creek, 1961 and 1962.

velocity at four different fish bypass widths. Note that the rate of change of water velocity at a distance upstream of the bypass is higher at lower approach velocities and at greater bypass widths.

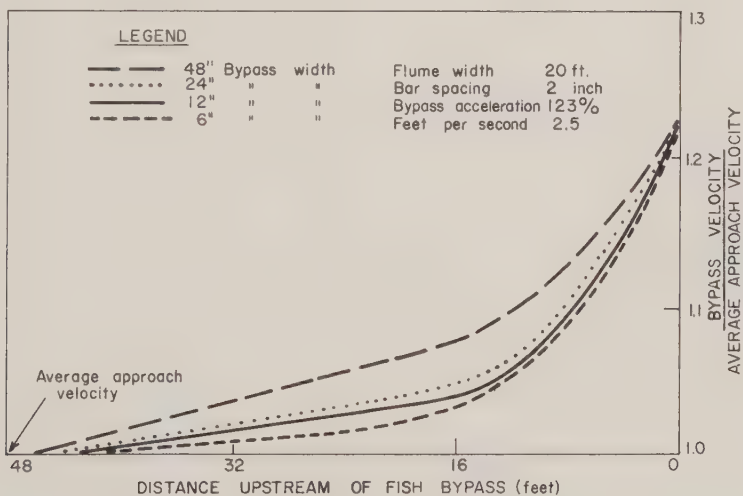


FIGURE 32. Velocity distribution upstream of louvers with bypass widths from 6 to 48 inches, Robertson Creek, 1961.

Vertical velocity distribution at fish bypass.

Hydraulic design criteria for fish bypasses require that they must, as nearly as possible, have a uniform velocity distribution over their discharge area at all expected approach velocities and depths.

The vertical distribution of velocities in the two types of bypasses used in the Robertson Creek louver tests is shown in Figure 33. The floor-type bypass used in 1960 was patterned after the Tracy design which was modified by hydraulic model studies undertaken by engineers of the Department of Fisheries

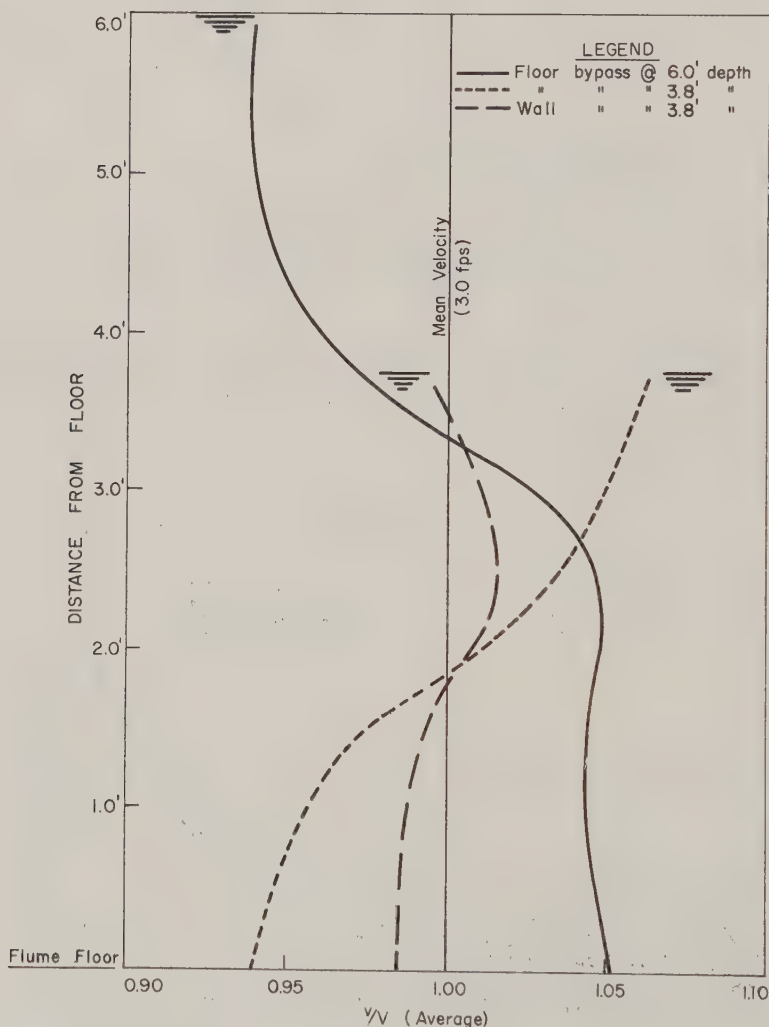


FIGURE 33. Vertical velocity distribution at entrance to floor and wall-type fish bypasses, Robertson Creek, 1960, 1961 and 1962.

in connection with the proposed louver installation on the Puntledge River, Anonymous (loc.cit.).

The test data indicates that there are no significant differences in velocity distribution between the two types of bypasses tested.

General Summary and Conclusions

The Fish Culture Development Branch of the Department of Fisheries of Canada conducted louver guiding tests on juvenile salmon at Puntledge River and Robertson Creek in British Columbia during the period 1957 to 1962. These tests were carried out for the purpose of evaluating louvers as a method for screening young salmon at an existing and a proposed hydro-electric project on Vancouver Island.

A chronological account of the development of the testing program is presented along with the results and conclusions. The results emphasize the need for careful testing before the louver principle can be adopted as a solution to a specific screening problem. The percentage fish deflection obtained shows that the following guiding efficiencies of a single line louver array could be expected under the conditions tested:

Sockeye smolts.....	85-95%
Coho smolts.....	85-95%
Chinook fry.....	65-75%
Coho fry.....	20-30%

Several factors affected the efficiency of the louvers in varying degrees. The following general comments on these factors summarize the extent of the information gained from the experiments. It should be kept in mind that all the tests were conducted in clear water, and it is not known if the results can be extrapolated to turbid water conditions or not.

1. Approach velocity.

One important advantage of a louver installation over conventional screening is its effectiveness throughout a wide range of approach velocities. Guiding efficiency was not significantly altered when the approach velocity was varied between 1.3 and 3.8 feet per second.

2. Bar spacing.

One of the major problems in the operation of a louver installation could be the collection of trash on the bars. It is desirable, therefore, to have the louver bars spaced as far apart as possible. Results from tests to date indicate that sockeye and coho salmon smolt deflection remains high with bar spacings of up to six inches. If salmon fry are to be deflected, bar spacing of not more than two inches is recommended.

3. The fish bypass.

Without a satisfactory bypass any success a louver array may have in deflecting fish from a water intake is nullified. In addition, an unsatisfactory bypass changes the effect of other variables on deflection efficiency. For example,

altering both approach velocity and bar spacing, within the ranges tested, had no significant result on the guiding efficiency when the bypass was suitable. However, when the bypass was unsuitable these variables did have a pronounced effect on guiding success. Results of the tests point up the need of meeting at least two important bypass criteria. The first of these involves the width of the bypass. Where schooling, yearling salmon are involved, an 18-inch-wide bypass should be provided. Very large schools of salmon smolts might require even wider bypass openings. A six-inch-wide bypass proved satisfactory for chinook fry.

The second bypass criteria involves the relationship between the water velocity in the bypass and the approach velocity. If a reduction in velocity occurs within the bypass, serious losses in guiding efficiency may result. Considering all data, a bypass velocity of about 140 percent of the approach velocity is recommended.

4. *Lighting.*

Reductions in guiding efficiency of about 10 percent occurred when the louver array was illuminated by overhead lights. A similar reduction occurred when the flume in which the louvers were installed was covered completely by a light-proof roof. Consequently, it is recommended that a louver installation should be illuminated by natural light only.

5. *Species of fish.*

Each species of fish reacts differently to louvers, and even fish of the same species react differently at different stages in their life history.

6. *Tandem louver arrangement.*

When louvers are installed in tandem the secondary line may be less efficient than the primary line. Results obtained in 1960 show that the second line of louvers was 77 percent as effective as the first line in deflecting sockeye salmon smolts. The tandem louver arrangement is, however, a practical means of increasing the overall guiding efficiency of a louver installation.

7. *Vee-louver arrangement.*

The experiments conducted in 1962 showed that the "Vee" configuration was satisfactory for guiding sockeye and coho salmon smolts. However, with chinook fry, it was found desirable to separate the converging louver lines by a center wall.

Hydraulic studies conducted during the Robertson Creek louver tests determined that the head loss for a long louver array with two-inch bar spacing

could be calculated from the formula $\Delta H = 1.62 \frac{V^2}{2g}$. Other hydraulic studies determined that the rate of velocity acceleration along the louver line is higher at low approach velocities and at greater bypass widths.

From the results of the tests on the Puntledge River the Department of Fisheries prepared two alternative designs for a full-scale louver system suitable for inclusion in the B.C. Hydro Puntledge power canal intake works. Both

alternatives included a tandem louver arrangement which it was believed would screen out approximately 90 percent of the downstream migrating chinook fry and steelhead smolts entering the canal.

Results of tests conducted at Robertson Creek indicated that a single line louver installation could provide a practical solution to the problem of screening sockeye and coho smolts from the water intake of the proposed hydro-electric development of the Stamp River.

ACKNOWLEDGMENTS

The results of the louver studies reported in this paper are the product of the contributions of many of the Pacific Area staff of the Department of Fisheries of Canada.

K. C. Lucas, P. Eng., formerly Senior Engineer (Research) and now Assistant Director, Pacific Area, was closely associated with all the work reported in this paper. He initiated the studies of louvers at the Puntledge River in 1957, and prepared a manuscript report on this work from which a part of the present paper is based. He also supervised the planning and construction of the Robertson Creek test flume and helped supervise the planning and conduct of the louver tests at Robertson Creek from 1960 to 1962.

E. W. Burridge, formerly District Biologist at Nanaimo, B.C., and now Chief, Fish Culture Development Branch, Ottawa, was a co-leader of the 1957 Puntledge flume tests and contributed many valuable ideas in these pioneer louver studies with chinook salmon fry. D. MacKinnon, Senior Biologist, supplied experienced biological consultation from 1958 to 1962. Project biologists who were associated with the tests include W. J. Schouwenburg, K. J. Jackson, and I. S. Todd.

The tests would not have been possible without the excellent experimental facilities provided by the Department's engineering staff. Besides the junior author, engineers who contributed substantially to the creation of the Puntledge and Robertson Creek test flumes were: M. J. Holden, P.Eng.; R. A. Fahlman, P.Eng.; J. P. Parkinson, P.Eng.; K. H. Kupka, P.Eng.; G. O. Nielsen and B. A. Heskin. Special mention should also be made of Technicians H. J. Schroder and R. E. Elvidge for their help in conducting the field studies.

C. H. Clay, P.Eng., Chief Engineer and R. E. McLaren, Chief Biologist, Pacific Area, were responsible for overall direction and co-ordination of the louver studies. Their active support and encouragement during all stages of the program are gratefully acknowledged.

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